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ELF Communications System Ecological Monitoring Program: A Summary Report for 1982-1991

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The U.S. Navy initiated an ecological monitoring program in 1982 as a part of its environmental quality program for its extremely low frequency (ELF) radio transmitting stations in Wisconsin and Michigan. Investigators have completed and reported work each year through 1991. This report describes 13 projects comprising the ecological monitoring program and the findings through 1991. Studies in Wisconsin have been completed, with no indications that ecological relationships have been influenced by electromagnetic fields produced by the ELF radio transmitter in that state. Studies in Michigan are continuing.

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ABSTRACT

An ecological monitoring program was initiated in 1982 by the U.S. Department of the Navy near its extremely low frequency (ELF) radio transmitting facilities in northwestern Wisconsin and in the central part of the Upper Peninsula of Michigan. The program was a progression from research completed in laboratories during the 1970s to investigate biological influences of exposure to ELF electromagnetic fields. The ELF radio transmitting facilities are described. The findings in the tenth year of conducting 13 ecology projects involving 73 indicators of biological and ecological sensitivity to ELF electromagnetic fields are summarized. Electric and magnetic field intensities and cumulative exposure are listed.

PREFACE

In 1982, the U.S. Department of the Navy initiated a program to monitor selected plants and animals and their ecological relationships in the vicinity of its ELF Communications System in northwestern Wisconsin and in the central part of the Upper Peninsula of Michigan. The purpose of the program is to identify whether changes occur that can be attributed to the electric and magnetic fields produced by the Naval Radio Transmitting Facilities at Clam Lake, Wisconsin and Republic, Michigan.

Research teams from Michigan Technological University (Houghton), Michigan State University (East Lansing), the University of Minnesota (Duluth), the University of Wisconsin (Parkside), and the University of Wisconsin (Milwaukee) have contributed to the program, which is funded entirely by the Department of the Navy. The University of Wisconsin investigators have completed their studies at Clam Lake. The Michigan and Minnesota investigators are continuing their studies near Republic.

IIT Research Institute (IITRI) coordinates the ecological studies, and provides engineering support to the research teams. The Michigan Department of Natural Resources also provides management support (including permits to conduct research on state forest lands) to the investigators. The U.S. Forest Service provided similar services when studies were conducted in the Chequamegon National Forest in Wisconsin.

Principal investigators prepare reports each year to describe their activities and document their findings. The reports are reviewed for scientific merit by selected peers, then compiled by IITRI after peer review comments are accommodated by the investigators. The compilations, without further editing by IITRI or the Department of the Navy, are forwarded to the National Technical Information Service (NTIS, U.S. Department of Commerce) for unlimited access by the public. Investigators also are encouraged to publish their findings independently in professional journals and present their results in public forums and at scientific conferences.

The yearly reports by principal investigators are written mainly for scientists, engineers, and others interested in all of the details of each project. The design of each project is discussed, the methods used to conduct each study are described, the statistical tests applied to findings are described, and data are analyzed extensively. Findings are interpreted with regard to electromagnetic field exposure, thei importance to forest management, and their contribution to the biological sciences and knowledge of ecological relationships. The reports probably contain much more information than is desired by other readers. For those interested in all of the details, however, those reports should be studied rather than this summary.

A summary report is prepared by IITRI each year to describe program results. The summary reports are forwarded to the NTIS for unrestricted public access. Additionally, the compiled yearly reports and the yearly summary reports are distributed to the Library of Congress, state libraries in Wisconsin and in Michigan, and libraries in the vicinity of the Naval Radio Transmitting Facilities.

It has been 10 years since the ecological monitoring program was begun. Three projects have been completed in Wisconsin, 10 others are continuing in Michigan, and a little more than two years of full-time, full-power ELF transmitter operations (and therefore, ELF electromagnetic field exposure) have been completed. For these reasons, a somewhat more extensive summary of the ecological monitoring program is reported this year.

Three ecosystems are being monitored:

- the upland forest ecosystem
- the wetlands ecosystem
- the aquatic ecosystem

Three kinds of studies are included in the ecological projects. Those studies, and the special strength of each, are:

- Studies of individuals; precise identification of small biological changes is possible
- Studies of populations; a collective response to environmental change can be detected
- Studies of communities; the consequences of a response to environmental change can be identified

There are eight projects for monitoring the upland forest ecosystem. The relationships among the projects can be illustrated as follows, starting with the most basic organism:

- Soil amoebae. A population impact could reduce or increase numbers of amoebae in soil, or an impact on feeding or reproduction of the amoebae community could affect:
- Soil bacteria and fungi, which are needed in large numbers (population) to decompose plant material and aid new plant growth (community functions). Impacts on soil bacteria and fungi could influence:
- Soil and litter animals, which break down plant material to produce nutrients in soil. Impacts on individual species and their populations, or on their community function of decomposing (with bacteria) plant material, could affect:
- Trees and plants, which provide food and habitat for forest animals and birds. Impacts on the growth of individual species of trees and plants, or on their reproduction, could affect:
- Native bees, which pollinate plants, and thereby contribute to the vigor and vitality of the upland forest ecosystem. Impacts on nesting of individuals, the survival of bee populations, or their community behavior, could affect:

- Animals and birds, which need trees, plants, and soil and litter animals (insects and worms) for their survival.

Wetlands are important because they provide food and habitat for many species of animals. The survival of wetlands, and therefore their inhabitants, depends on several key processes that have been studied in a wetlands project. These processes are:

- Decomposition of plant material, which produces the vegetative soils that characterize wetlands. An impact on decomposition could affect:
- Nutrients, which are needed in wetlands for succeeding generations of plants. Impacts on nutrients could affect:
- Succeeding generations of plants, which might respond differently to environmental conditions such as light and carbon dioxide. An impact on the response of plants (opening and closing of stoma to collect and store energy) could fundamentally change wetlands.

Three projects are included in the ecological monitoring program to study the aquatic ecosystem. As in the case of the upland forest ecosystem, the relationships of these projects can be illustrated by starting with the most basic aquatic organism:

- Algae, which provide food for aquatic insects. An impact on individual species, how they colonize and where they accumulate (their population, so to speak), or their photosynthetic and respiratory activity (community functions), could affect:
- Aquatic insects, which gather, shred, filter, and consume plant material such as algae and leaves from trees. Impacts on individual species or their populations, or on their processing or consumption of plant material, could affect:
- Fishes, which consume aquatic insects. An impact on individual species and their abundance, or on their movements, could fundamentally change the aquatic ecosystem.

This report summarizes most of what has been done on a continuing basis in the ecological monitoring program during the past 10 years. The emphasis of the report is on the biological and ecological observations that have been made, and how those observations have been interpreted by investigators.

It is not yet possible to draw firm conclusions from most of the projects about ecological influences of exposure to ELF electromagnetic fields. With three exceptions, projects have not yet been completed. There are, however, some indications of trends in some results. At least one more year of observation is essential to draw conclusions from most projects, and several years more may be needed before confident conclusions can be reached from others.

The conclusions that have been drawn from completed projects are the following:

- Slime mold, a primitive organism found in upland forest settings, does not appear to be affected by electromagnetic fields produced by the Navy's ELF Naval Radio Transmitting Facility near Clam Lake, Wisconsin.

- Wetlands ecosystems do not appear to be sensitive to exposure to ELF electromagnetic fields.
- No evidence has been found that the ELF Naval Radio Transmitting Facility near Clam Lake, Wisconsin has an effect on resident or migrant birds.

The trends that have been identified by investigators of continuing projects that require additional observations for confident verifications are the following:

- There are no indications of ELF electromagnetic (EM) field exposure effects on soil amoebae.
- There are no indications of ELF EM field exposure effects on soil bacteria or fungi.
- There are no indications that most species of soil and plant litter animals (insects and earthworms) are sensitive to ELF EM field exposure, but an observed change in earthworm reproductive characteristics near the ELF transmitting antenna remains unexplained.
- Young and relatively mature trees and herbs do not appear to be sensitive to exposure to ELF EM fields. However, red pine seedlings growing near the ELF transmitting antenna and a ground terminal are not growing as vigorously, and show a deficit in some nutrients, compared with seedlings growing distant from the ELF antenna.
- Native bees do not appear to be affected by ELF EM field exposure in terms of behavior or reproduction, but mortality during winter has been slightly higher near the ELF transmitting antenna than at distant nests. The compass orientation of nests may be an influencing factor.
- Based on observations of two species of small mammals and two species of resident birds, no indications of ELF EM field exposure effects have been identified on upland forest mammals or birds.
- Resident and migrant birds in Michigan have not shown any indication of sensitivity to ELF EM field exposure.
- The Ford River ecosystem in Michigan experiences substantial changes from year to year in many ways. Observed changes have been related to weather conditions that affect river flow and water temperature. No evidence has been found that would associate observed changes to ELF EM field exposure of aquatic plants, insects, or fish.

All of the work documented in this report has been funded entirely by the U.S. Department of the Navy through its Space and Naval Warfare Systems Command (SPAWARS) via a series of research contracts with IITRI. Advice on conducting research has been provided not only by the SPAWARS staff, but by representatives of the Chief of Naval Operations (Director of Communications), the Naval Medical Command, the Naval Facilities Engineering Command, the Naval Telecommunications Command, the U.S. Forest Service (Chequamegon National Forest, Park Falls District), and the Michigan Department of

Natural Resources. IITRI and its associated contractors at the University of Wisconsin, Michigan State University, Michigan Technological University, and the University of Minnesota wish to acknowledge that support.

Respectfully submitted,
IIT RESEARCH INSTITUTE

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Approved:

R. D. Carlson, Director
ELF EM Compatibility Assurance

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FIGURES (continued)

FIGURES (continued)

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THE ELF COMMUNICATIONS SYSTEM ECOLOGICAL MONITORING PROGRAM: A SUMMARY REPORT FOR 1982-1991

1. INTRODUCTION

1.1 Origins of the Program

Engineers and scientists have shown an interest in biological responses to electric and magnetic fields since at least the 1880s. However, until about World War II the mainstream interest in biological phenomena associated with electricity remained in the area of contact with electric currents in wires. Then the development of radar was followed soon thereafter by the recognition that very intense, short-wavelength energy could produce destructive heating in body organs. It became necessary to limit exposures to high-frequency, intense electromagnetic fields produced by some types of electronic devices.

Another early interest in electric and magnetic field biological effects was related to delivering electric power to consumers. Electrical engineers recognized that voltages could be produced in soil near ground terminals at generating plants and substations. The phenomenon, called step potential, could produce detectable currents in humans and animals. Engineering standards were soon developed to limit step potentials to safe values.

Except for some pioneering work at Johns Hopkins University in the United States with linemen working on high-voltage power transmission lines and work in Germany with humans isolated from atmospheric electric fields, there was little interest in biological response to very-long-wavelength energy when the U.S. Navy commenced research on ELF communications in the late 1950s. As research on ELF communications continued through the 1960s, the Navy took the initiative to conduct exploratory research on biological responses to ELF electric and magnetic fields both in soil and in air.

The Navy had accumulated a considerable body of knowledge about ELF electric and magnetic fields and biological responses by the time it prepared its first environmental impact statement (EIS) in 1972. Investigators at universities, in government, and in industry had reported their findings, which were summarized in the 1972 EIS.[1] Increasingly more complex experiments and ecological surveys continued until 1977. Results were again reported independently by investigators, and were summarized in a 1977 EIS prepared by the Navy.[2]

The Navy had concluded in both the 1972 and 1977 environmental reports that an ELF Communications System could be operated with little risk that adverse biological effects would be produced by ELF electric and magnetic fields. Nevertheless, the Navy announced that ecological

monitoring would be initiated prior to operating ELF communications facilities, and would continue thereafter.

The National Academy of Sciences (NAS) conducted an independent assessment of ELF electric and magnetic field biological effects in 1975-1977. The NAS also concluded that the risk of adverse biological consequences from an ELF Communications System was small.[3] The NAS concluded that sufficient laboratory research had been completed by the Navy, and it outlined the elements of an ecological monitoring program.

Following presidential approval to upgrade its experimental ELF facility in Wisconsin to an operational transmitter and to build a second transmitter in Michigan, the Navy announced its plan in 1981 to initiate an ecological monitoring program in the two states.[4] The plan was coordinated with state agencies and the U.S. Forest Service, and proposals for research were invited.

More than 100 proposals were received. The proposals were evaluated for scientific merit and reviewed for other qualifications, and the ecological monitoring program was initiated in mid-1982.

1.2 THE FUNDED PROJECTS

Thirteen projects were selected to constitute the ELF Ecological Monitoring Program. Several criteria were used to make the selections. First, it was desirable to include projects that represented the three main ecosystems in the vicinities of the ELF transmitter facilities:

- the upland forest ecosystem
- the wetlands ecosystem
- the aquatic ecosystem

Another criterion was the choice of species. Meaningful studies require sufficiently large populations for results to be both scientifically and statistically meaningful. Species common to the regions were therefore preferred over rare or endangered species. Rare and endangered species have special significance, but their numbers are too small for the studies intended in this program. Moveover, rare and endangered species are protected and studied by other federal and state programs.

A third criterion for funding projects was to include several levels of biological complexity in the program. The approved projects represent the following three levels of biological organization:

- the organism
  - characteristics of individuals (e.g., behavior and physiology)
- the population
  - studies of many individuals of the same species (e.g., species density, distribution, and abundance of offspring)

- the community
  - the integrated responses of many species (e.g., the diversity of species, their productivity, nutrient cycling)

Another criterion was what was reported in the literature about electromagnetic field effects on biology. Most of the literature relates to biological effects that have been observed in laboratories where the only variable is electromagnetic (EM) field intensity. Other environmental factors are maintained at constant values so that they can be isolated from the EM variable of interest.

Research on whole-body exposure has demonstrated that ELF EM fields can affect physiological functions such as growth and reproduction; brain functions (neurophysiology) such as learning and behavior; and blood chemistry, among others. Practically all observed effects have occurred at EM field intensities that are much higher than EM fields measured in the environment. Despite years of research, very little is actually known about how EM fields influence biota; that is, biological mechanisms remain essentially unknown. Moreover, it is not known whether biological effects observed in the laboratory under strict conditions also would occur in natural settings where many environmental variables influence plants and animals throughout their life cycles.

Scientists also have reported that EM field effects have been observed on organs and cells that have been removed from bodies and maintained in laboratory solutions. Effects typically occur at field intensities that are lower than needed to produce effects on intact live bodies or plants. It is difficult, however, to determine whether simple EM field relationships exist between effects observed in *in vitro* (isolated biological matter) experiments and in *in vivo* (whole-body) experiments.

There was practically no literature available in 1982 reporting ecological studies of EM fields other than exploratory surveys done by the Navy. There are only a few studies comparable to those funded by the Navy; most notable are *in-situ* studies of biota in high-voltage line rights-of-way funded by the Bonneville Power Administration.[5]

Even though knowledge is limited about how EM fields influence biological functions specifically, and what other environmental conditions might be important in producing EM field effects, the literature was helpful to scientists designing proposals and to the Navy in selecting proposals for funding.

The projects that make up the ELF Ecological Monitoring Program are listed in Table 1. The applicable ecosystem and level of biological organization for each project also are listed in the table. Another perspective of the projects and how each relates to the ELF Ecological Monitoring Program is provided in Figure 1.

TABLE 1. THE ELF ECOLOGICAL MONITORING PROJECTS

Ecosystem	Project	Level of Biological Organization		
		Organisms	Populations	Communities
Upland Forest	Soil Amoebae	•	•	
	Soil Bacteria and Fungi		•	•
	Slime Molds	•		
	Soil and Litter Animals	•	•	•
	Trees and Herbs	•	•	
	Native Bees	•	•	
	Small Mammals and Nesting Birds	•	•	•
	Bird Species and Communities		•	•
Wetlands	Plants	•	•	
Aquatic	Algae, Insects, and Fish	•	•	•

Northwestern Wisconsin and the central part of the Upper Peninsula of Michigan are mostly upland forest settings. Projects concerning the upland forest ecosystem therefore make up most of the Ecological Monitoring Program. Wetlands represent a transition between upland forests and aquatic systems and are common in the Wisconsin region, but less common in Michigan. Although only one wetlands project was selected, the project included 11 wetland areas and three distinct studies.

Ponds, lakes, and rivers comprise the aquatic ecosystem. Because practically every pond and lake exhibits unique features, they are not suitable candidates for region-wide ecological surveys. Rivers are much more dynamic systems, and a river ecosystem was selected for aquatic projects.

As is evident from Table 1 and Figure 1, wildlife studies are not included in the ELF Ecological Monitoring Program. Most wildlife species are relatively free-ranging and influenced greatly by human activities. They therefore are not suitable subjects for ecological monitoring. The selected projects concentrate on basic ecological relationships, which if affected by ELF EM fields, would in turn likely impact wildlife. Furthermore, other more appropriate studies of wildlife are supported by the U.S. Forest Service and state departments of natural resources.

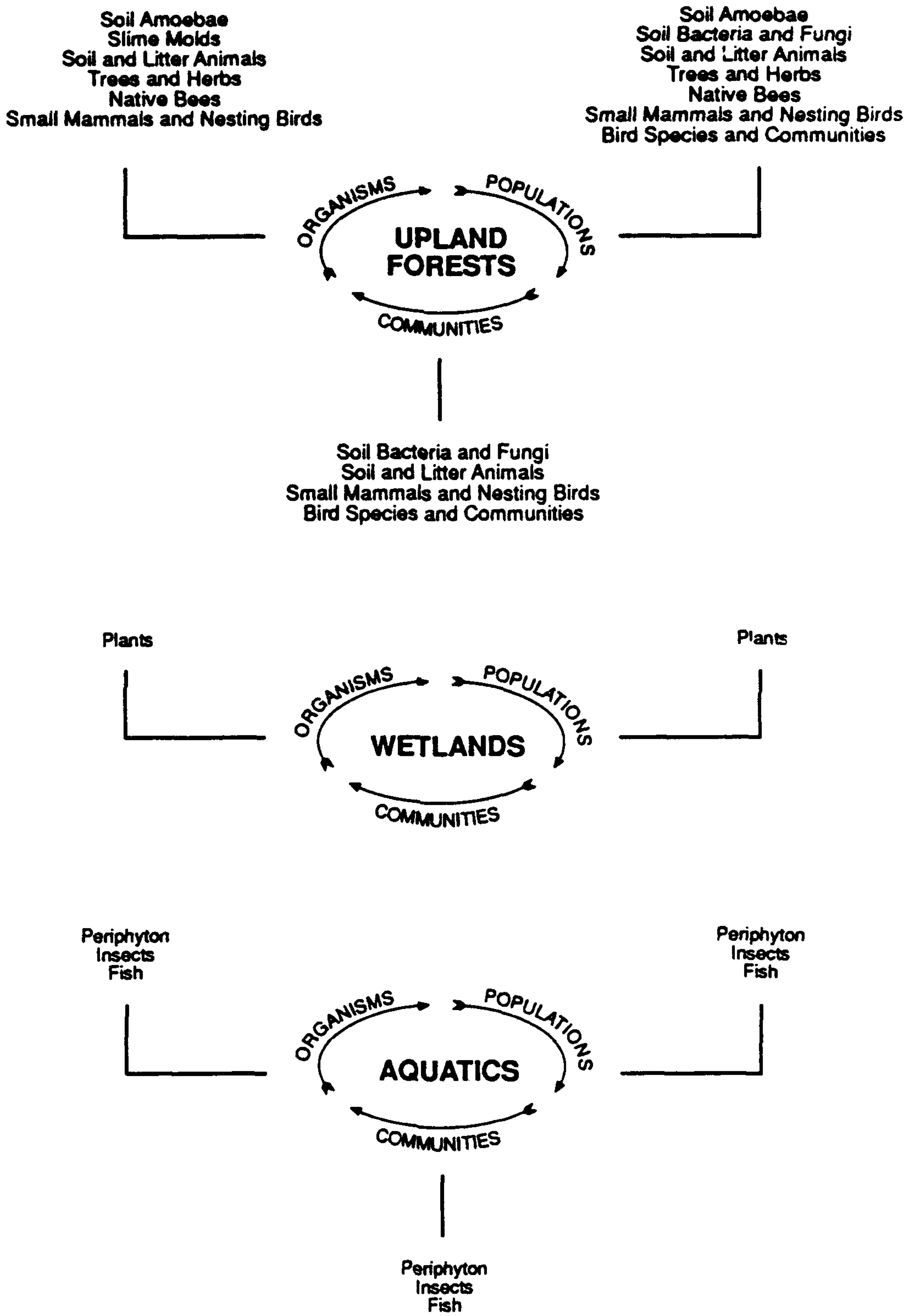


FIGURE 1. ECOSYSTEM PROJECTS AND THEIR BIOLOGICAL ORGANIZATION.

2. THE ELF COMMUNICATIONS SYSTEM AND ITS ELECTROMAGNETIC FIELDS

2.1 The Transmitting Facilities

An experimental ELF transmitter facility was built in the late 1960s near Clam Lake, Wisconsin in the Chequamegon National Forest. The facility was needed to develop methods for preventing electromagnetic interference on public utilities, to conduct transmission tests, and for engineering evaluations of equipment. The facility also provided a means for surveying whether ELF EM fields might influence ecological relationships.[6-18] The U.S. Forest Service and the Navy also made wildlife studies in the region.[19-24] The ELF transmitter facility in Wisconsin was converted to an operational transmitter in 1985.

A second ELF transmitter facility was built near Republic, Michigan in the early 1980s. The Michigan facility, located in the Escanaba River and Copper Country State Forests, was built as an operational facility and commenced test operations in 1986. Full-time operational status was achieved late in 1989.

The two transmitter facilities are now known as the Naval Radio Transmitter Facility (NRTF)-Clam Lake and the NRTF-Republic. Their locations are shown in Figure 2. The transmitters can be operated independently or as a single communications facility. Each facility includes a transmitter building, an overhead wire antenna, and antenna ground terminals. Important characteristics of each facility are listed in Table 2. A typical view of an overhead antenna, which looks much like an ordinary power line, is shown in Figure 3. Photographs of the transmitter buildings are shown in Figures 4 and 5. Each ground terminal is tailored for operational and safety purposes. Sketches of ground terminals are shown in Figures 6 and 7.

2.2 ELF Electromagnetic Fields

Voltages on vertical or horizontal wires above the ground produce an electric field in air. The overhead ELF antennas therefore produce electric fields. The electric field is called a transverse, vertical electric field, and is measured in volts per meter (V/m). Voltage on ELF antennas is at a maximum near the transmitter connections and diminishes to nearly zero at each of the ground terminals. As listed in Table 2, the maximum voltage on the antennas is about 4000 V, and produces a maximum electric field intensity of about 150 V/m.

A visualization of an ELF transverse, vertical electric field in air is shown in Figure 8. Ordinary overhead power lines, being horizontal wires, also produce ELF transverse, vertical electric fields (at 60 Hz, versus 76 Hz for ELF antennas). The voltages on power lines remain essentially the same between substations and customers along the line, so the electric field intensity along the line also remains practically the same. Some typical electric field intensities produced by power lines are listed in Figure 8.

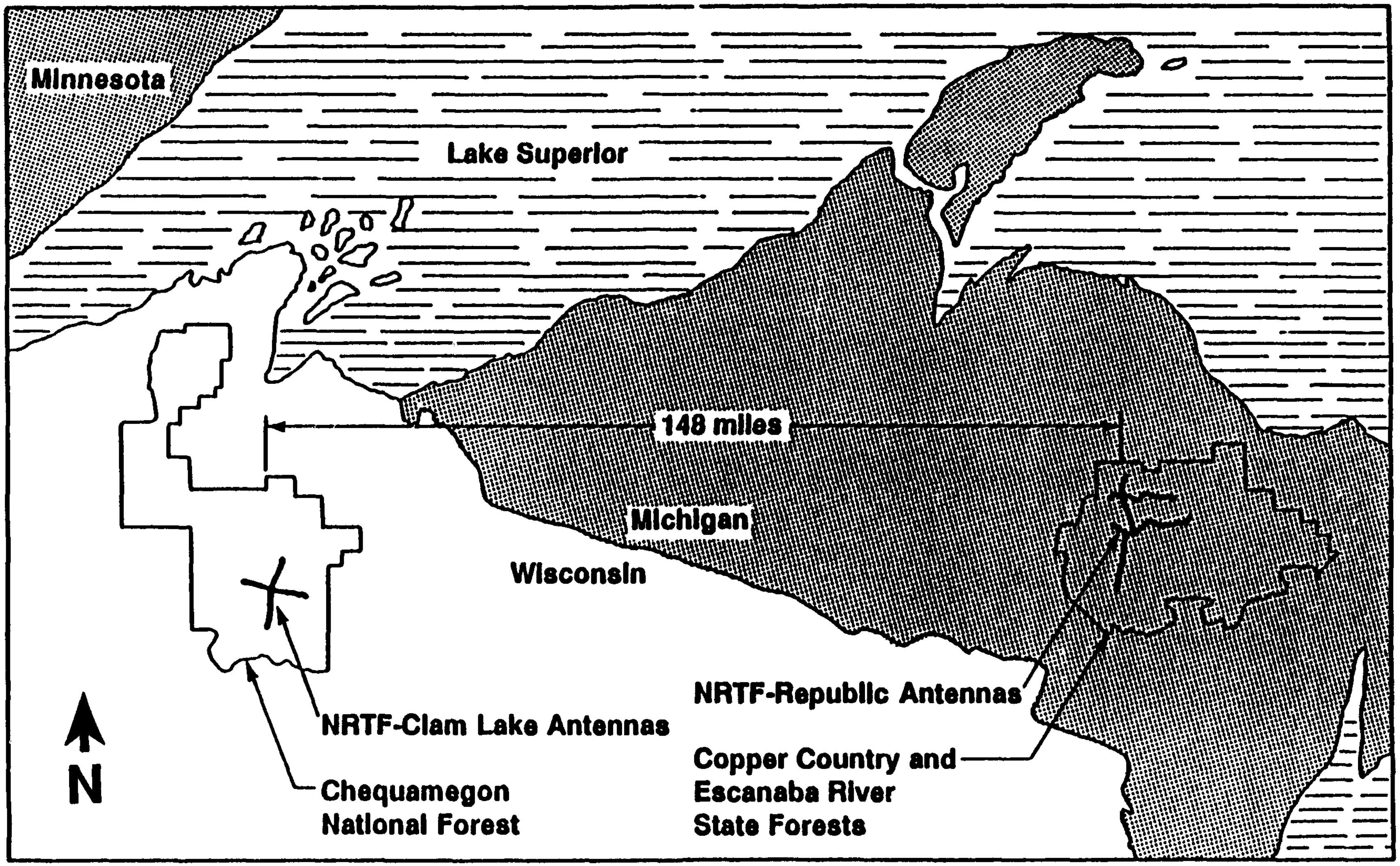


FIGURE 2. ELF COMMUNICATIONS FACILITIES IN WISCONSIN AND MICHIGAN.

TABLE 2. IMPORTANT CHARACTERISTICS OF THE ELF COMMUNICATIONS SYSTEM

Characteristic	NRTF-Clam Lake	NRTF-Republic
Transmitter frequency	76 Hz (± 4 Hz modulation)	76 Hz (± 4 Hz modulation)
Number of antenna elements	2	3
Antenna configuration	cross	letter F
Total antenna miles	28	56
Maximum antenna current, A	300	150
Antenna operating voltage, V	4000	4000
Maximum transverse vertical electric field in air under antennas, V/m	150	150
Average longitudinal electric field in soil along antenna rights-of-way, V/m	0.14	0.07
Average magnetic flux density at the surface under antennas, gauss	0.06	0.03
Number of buried ground terminals	4	6
Criteria for maximum simulated body current near ground terminals	2 mA in 1 m, 5 mA in 4 m	2 mA in 1 m, 5 mA in 4 m

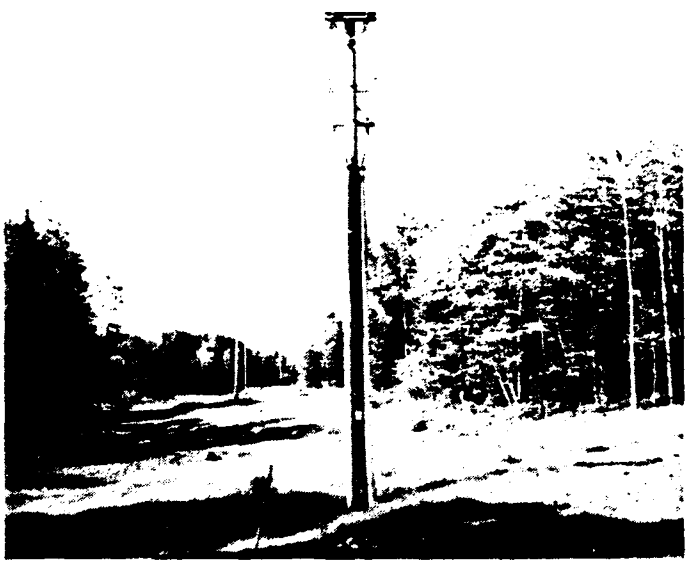


FIGURE 3. TYPICAL VIEW OF AN OVERHEAD ELF ANTENNA.

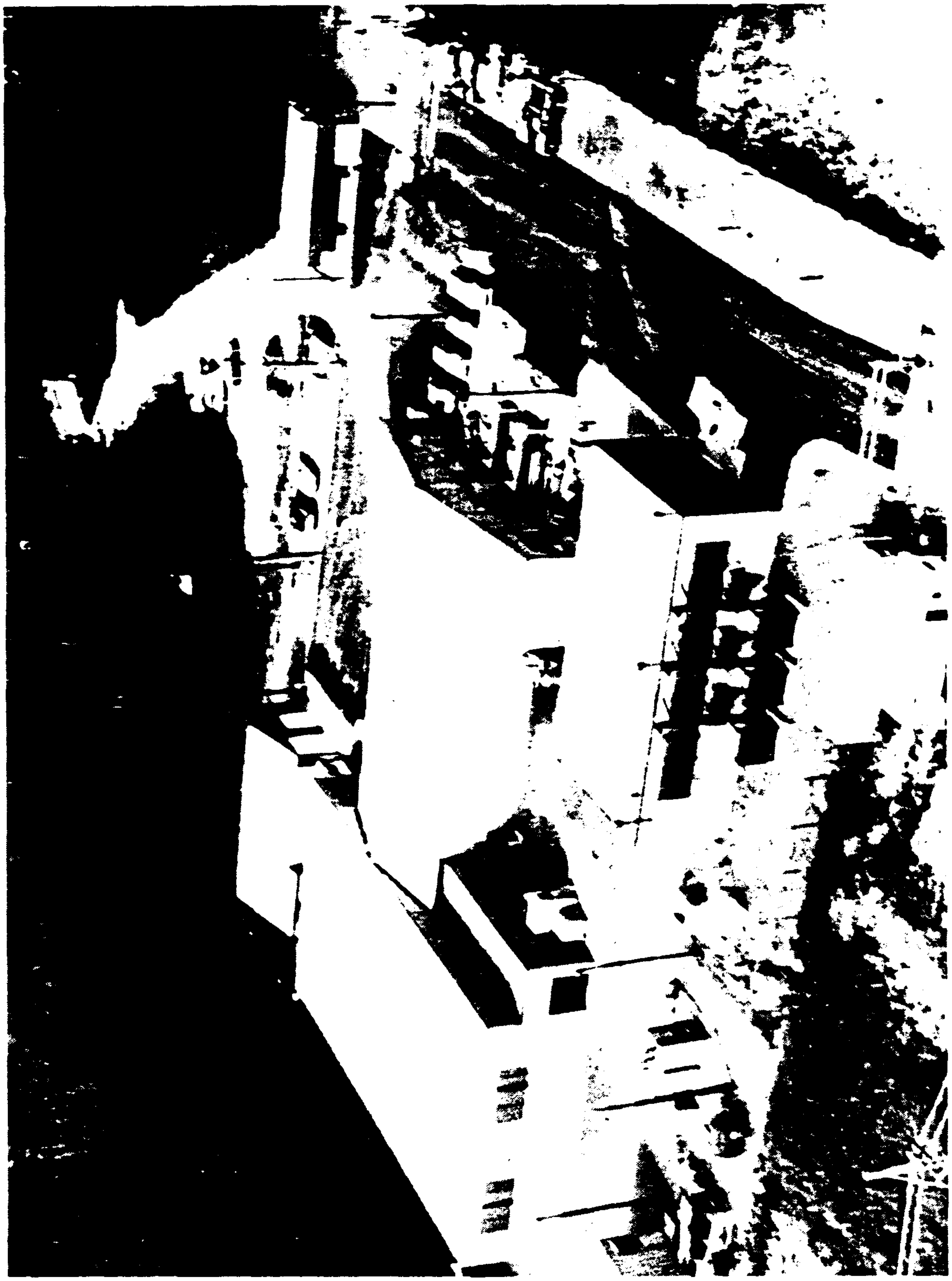


FIGURE 4. THE NRTF-CLAM LAKE.

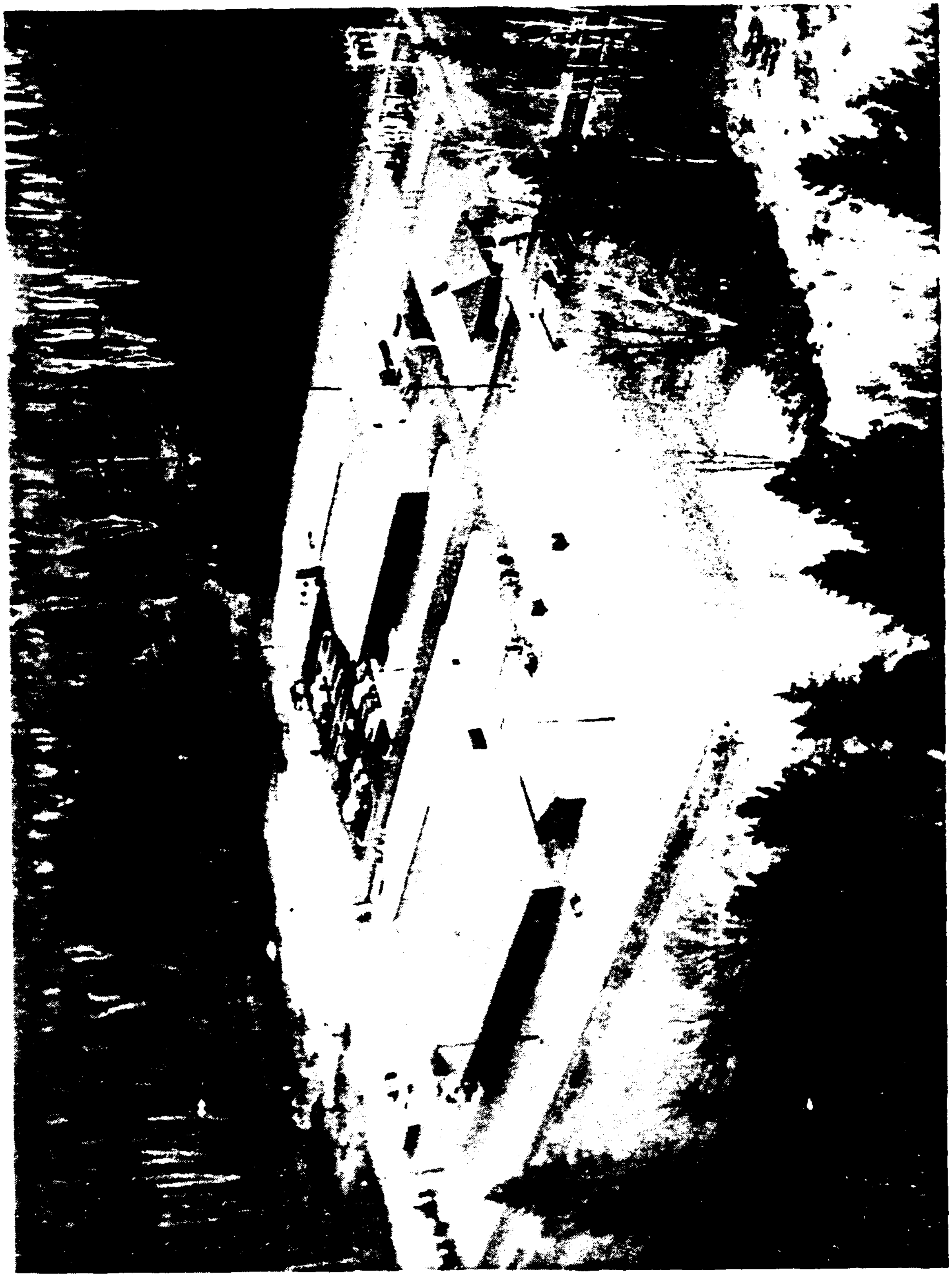


FIGURE 5. THE NRTF-REPUBLIC.

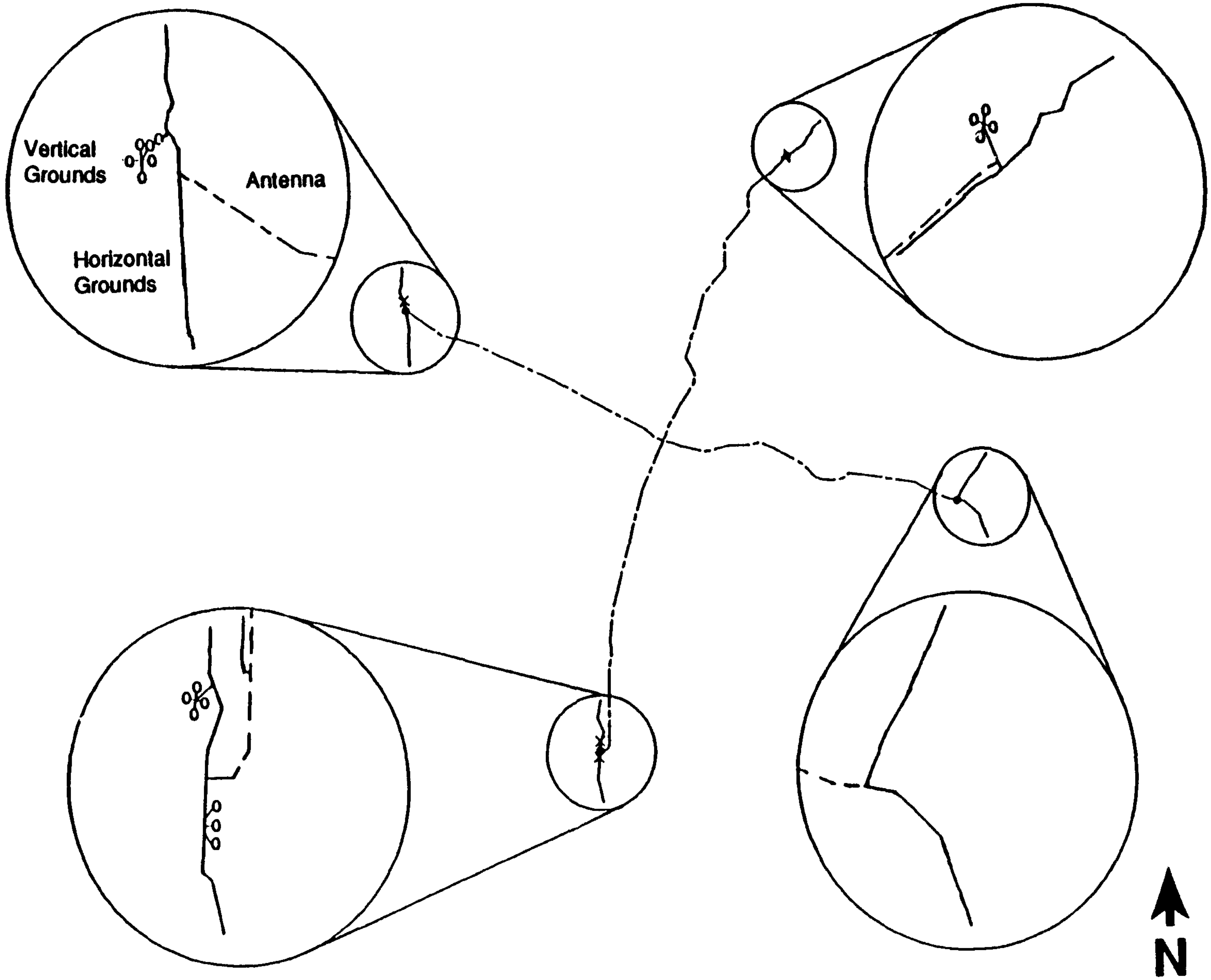


FIGURE 6. GROUND TERMINAL CONFIGURATIONS AT THE NRTF-CLAM LAKE.

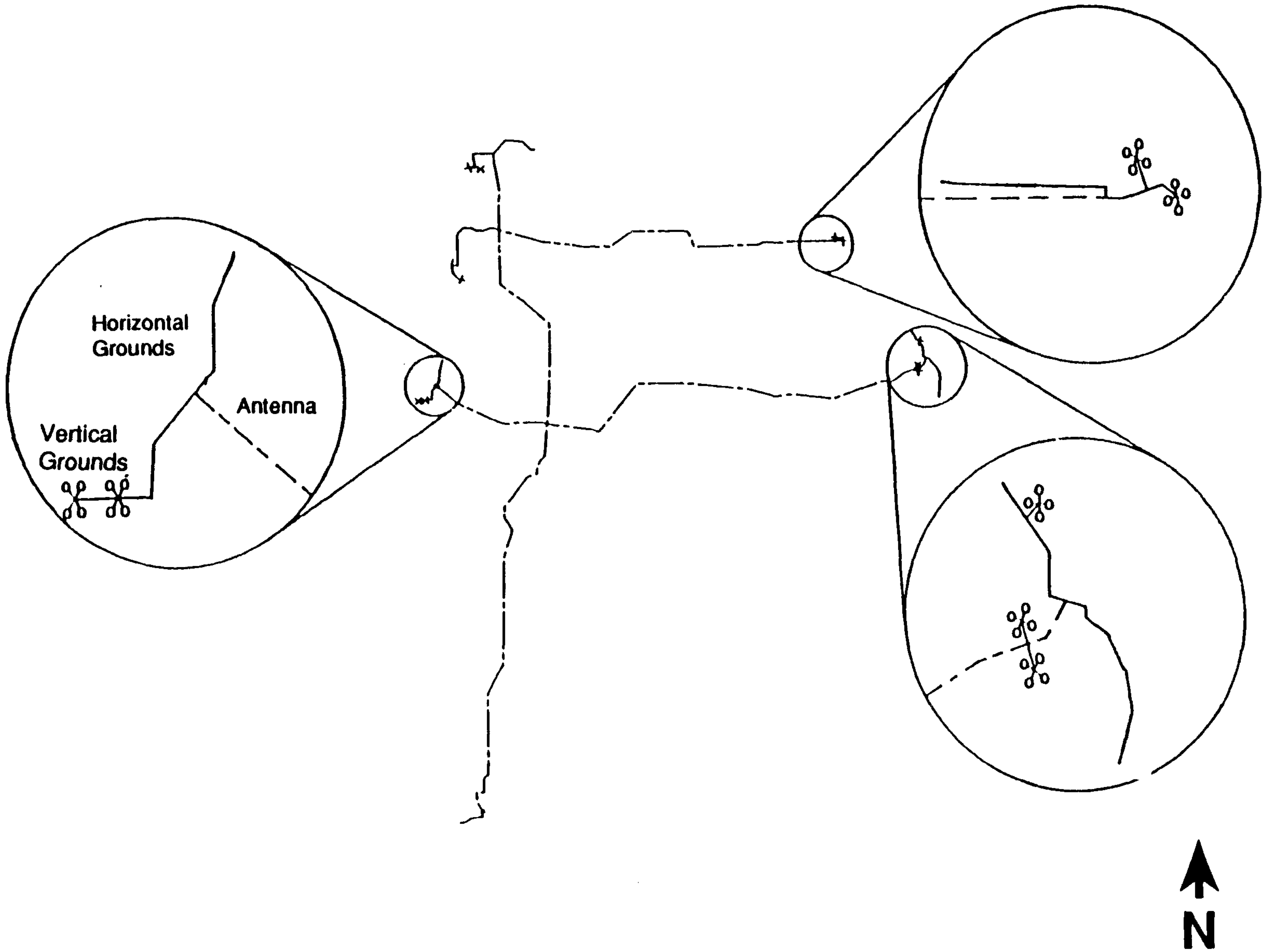
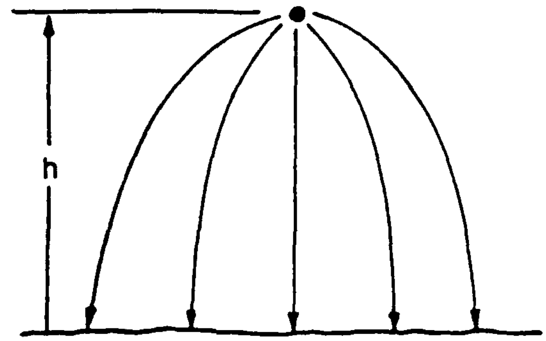


FIGURE 7. GROUND TERMINAL CONFIGURATIONS AT THE NRTF-REPUBLIC.

Transverse Electric fields in Air:

- are proportional to voltage
- decrease as line height increases
- do not penetrate into earth

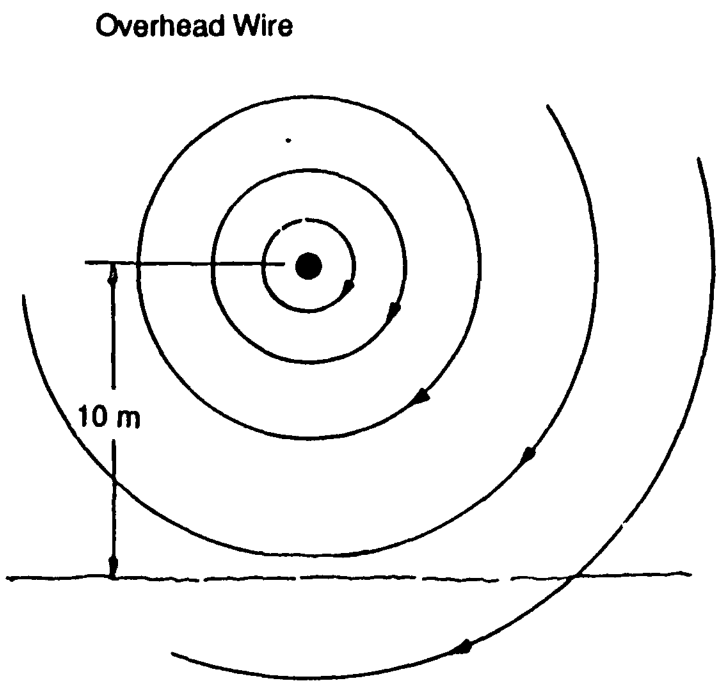


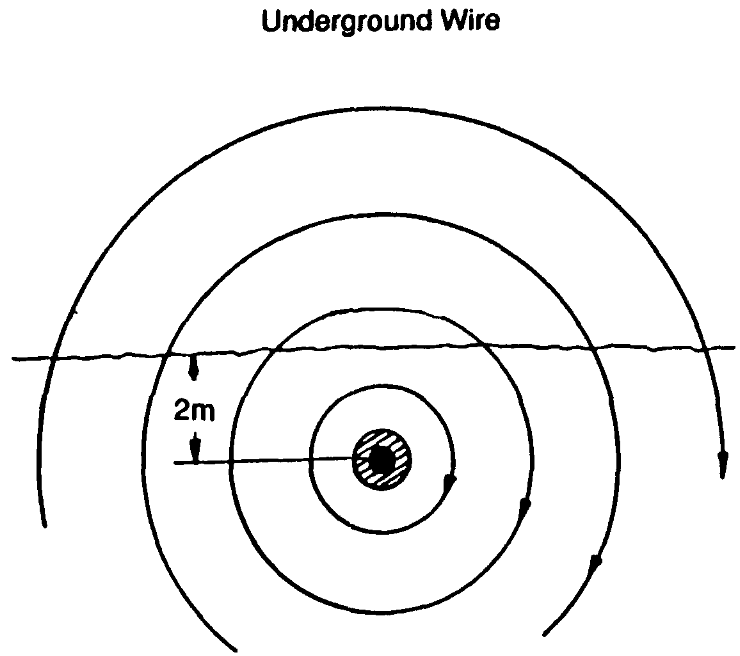
Overhead Source	Electric Field Intensity, Volts per Meter (V/m)
ELF antenna	150 (maximum)
7.2 kV customer distribution line	130
69 kV high-voltage transmission line	500
345 kV EHV transmission line	5000
765 kV UHV transmission line	8000

FIGURE 8. VISUALIZATION AND TYPICAL VALUES OF TRANSVERSE, VERTICAL ELECTRIC FIELDS IN AIR.

Current in a wire produces a magnetic field around the wire. Magnetic fields at ELF are measured as magnetic flux densities in gauss or tesla (gauss are used for the ELF program). Magnetic field intensity increases when current increases. A visualization of magnetic fields and some typical examples are given in Figure 9. Note from Table 2 that the antenna current at NRTF-Clam Lake is twice that at NRTF-Republic; therefore, the magnetic flux density at Clam Lake is twice that at Republic. Antenna current is the same all along an ELF antenna, so the magnetic flux density remains the same along the antenna. Power line currents, on the other hand, vary as customers use more or less energy, so magnetic flux densities along power lines are continually changing.

Magnetic fields are responsible for electric fields in soil that differ from electric fields in air. The electric fields in soil are called longitudinal electric fields. Field intensities are very variable because soil conditions influence their behavior. Longitudinal electric fields in soil are therefore best described in terms





Source	Magnetic Flux Density, Gauss
NRTF-Republic antenna	0.03
NRTF-Clam Lake antenna	0.06
EHV transmission line	0.30

The Magnetic Field Surrounding A Wire Is:

- proportional to current
- inversely proportional to distance
- the same in air as in soil

FIGURE 9. VISUALIZATION AND TYPICAL VALUES OF MAGNETIC FIELDS.

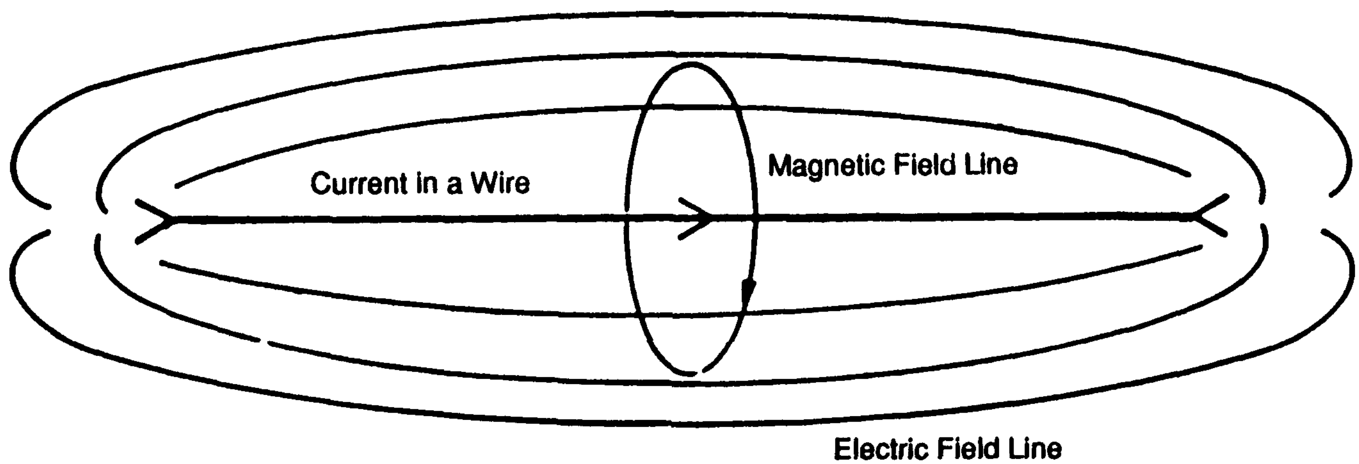
of averages of many measurements. A visualization of electric fields in soil and examples of their intensities are given in Figure 10.

2.3 Electromagnetic Field Exposures at Study Sites

Electric and magnetic fields produced at 60 Hz by power lines exist practically everywhere, because power lines are routed wherever people need electric energy. There is no evidence at present that biological effects would be more likely to occur at 76 Hz than at 60 Hz, or vice versa. It was therefore necessary to establish some 60 Hz and 76 Hz electric and magnetic field goals for the selected ecology projects. Since it is virtually impossible to avoid 60 Hz fields even in Wisconsin and Michigan forests, relationships were devised for the relative intensities of 60 Hz and 76 Hz fields at ecology study sites. Sites considered by investigators were examined for electromagnetic suitability before studies commenced. The criteria for study sites are listed in Table 3.

TABLE 3. ELECTROMAGNETIC FIELD EXPOSURE GUIDELINES FOR THE ELF ECOLOGICAL MONITORING PROGRAM

- 76 Hz electric and magnetic field intensities at sites selected for ELF exposure studies should exceed those at distant sites selected for comparisons by at least a factor of 10
- 60 Hz electric and magnetic field intensities at sites selected for ecology studies should be lower than 76 Hz electric and magnetic fields by at least a factor of 10
- 60 Hz electric and magnetic field intensities at sites selected for ecology studies should not differ by more than a factor of 10



Source	Electric Field Intensity in Soil, V/m
NRTF-Republic antenna	0.07
NRTF-Clam Lake antenna	0.14
EHV transmission line	0.10 to 0.05
Customer's electric service entrance	0.10 on average

FIGURE 10. VISUALIZATION AND TYPICAL VALUES OF LONGITUDINAL ELECTRIC FIELDS IN SOIL.

3. PROJECT DESCRIPTIONS

3.1 Design Requirements

Investigators interested in participating in the ELF Ecological Monitoring Program were required to describe their project designs in proposals submitted in 1982 (see Reference 19). Descriptions of studies and their justification were required, methods to be used to conduct each study had to be explained, and intended methods for analyzing results had to be identified.[25] Investigators were not required to measure 60 Hz and 76 Hz electric and magnetic fields. Those measurements are made by IITRI to ensure uniformity of methods for all projects. However, investigators were required to identify how other environmental factors would be accounted for that might be expected to influence their studies.

There was a fundamental difference in the way studies could be designed for Wisconsin and for Michigan. The NRTF-Clam Lake had been operated for research for about 10 years. It was not possible to obtain data in Wisconsin until a site was selected (i.e., not before 76 Hz electric and magnetic fields were produced). The NRTF-Republic site, on the other hand, had been selected years before construction, so it was possible to study ecosystems both before and after 76 Hz field exposure.

3.2 Upland Forest Ecosystem Project Descriptions

3.2.1 The Soil Amoebae Project

Soil amoebae are important to the upland forest ecosystem because amoebae consume soil bacteria and play a role in enriching soil. Should EM fields affect soil amoebae, the effect could have significant ramifications on the entire forest ecosystem.

The soil amoebae project is being conducted in Michigan at three sites: near the south end of the north-south antenna, near the south ground terminal, and about 10 miles from the south ground terminal. The study sites are identified in Figure 11. Environmental conditions important to soil amoebae are essentially the same at all three sites. Electromagnetic field exposures at 76 Hz are substantially different, however.

Amoebae are studied as organisms to determine whether EM field effects might impact growth. Studies at the organism level are statistically precise. The functions being examined are population size, feeding activity, and generation times.

3.2.2 The Soil Bacteria and Fungi Project

Soil bacteria and fungi are primary agents involved in decomposing organic matter. Decomposition is essential for soil to remain productive.

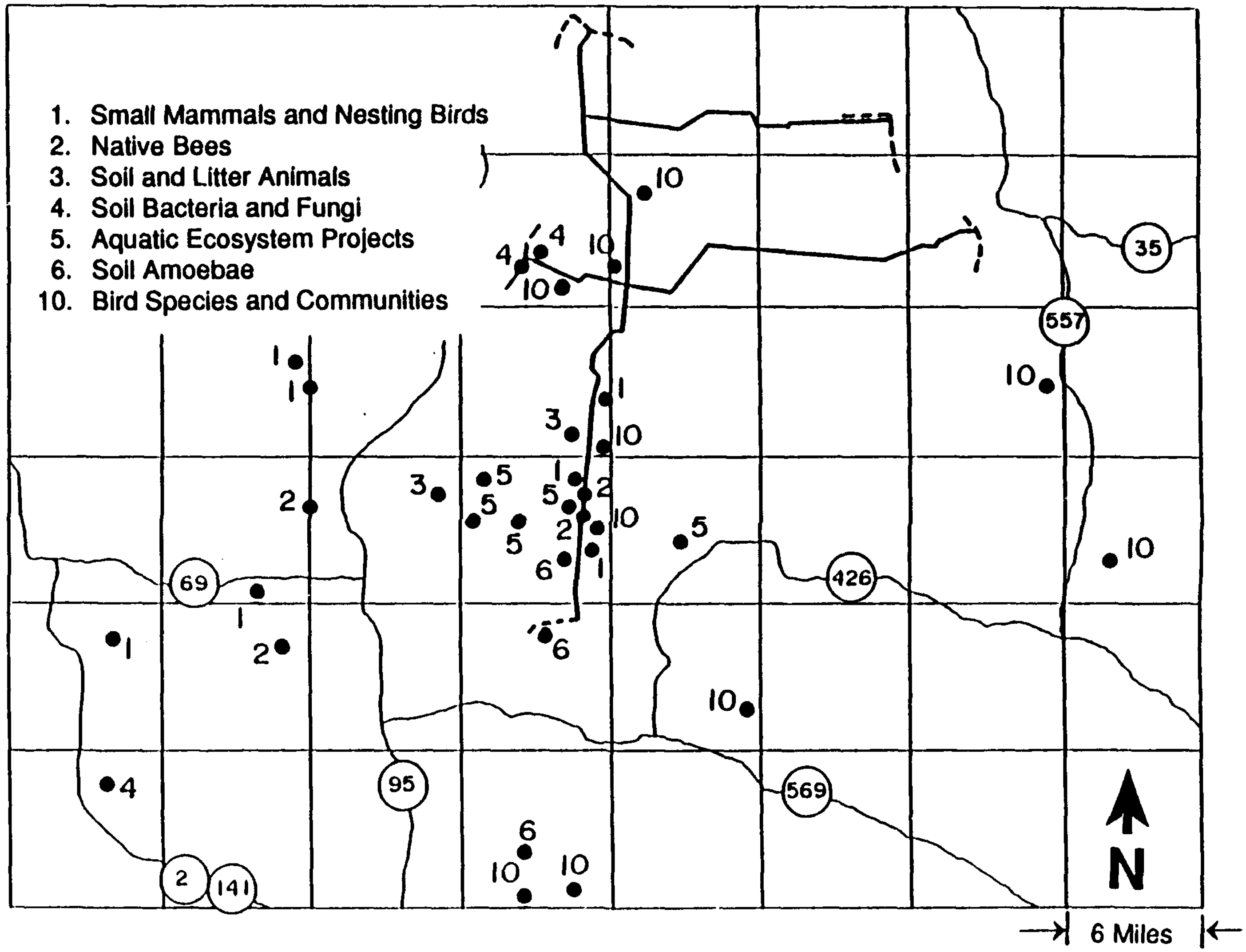


FIGURE 11. STUDY SITES FOR ECOLOGY PROJECTS IN MICHIGAN.

This project concentrates on two processes. One study has a population focus: bacteria near red pine tree roots. Bacteria near tree roots are important for tree growth. The other study focuses on decomposition of pine needles and hardwood leaves.

The soil bacteria and fungi project is being conducted at three sites in Michigan. As shown in Figure 11, two of the sites are located near the more southern of the two east-west ELF antennas. One serves as an antenna study site and the other as a ground terminal study site. The third site is located about 35 miles to the southwest. As for the soil amoebae project, important environmental conditions for soil bacteria and fungi are essentially the same at all sites, but 76 Hz EM field intensities are different.

3.2.3 The Slime Mold Project

Slime mold is an organism that exhibits characteristics of both a plant and an animal It is a primitive organism that has been studied extensively by biologists. It sometimes can be found in suburban settings as well as in forests. It can be recognized easily from its appearance: it often looks like a ringed growth on lawns.

The slime mold (*Physarum*) was studied in laboratory research funded by the Navy in the 1970s. The results of the research were inconclusive, and for that reason, a slime mold project was included in the Ecological Monitoring Program. The study (which has been completed) was conducted in Wisconsin at the three sites identified in Figure 12. Two of the sites were near the west end of the east-west antenna and its ground terminal. The third site was located about 10 miles east of the north leg of the north-south antenna.

Slime mold was also examined in a laboratory on the Parkside campus of the University of Wisconsin to complement the field project. Cell division, ATP content, and oxygen consumption were studied. All are indicative of the organism's physiology.

3.2.4 The Soil and Litter Animals Project

Soil insects having jointed legs and no vertebrae are called arthropods. Arthropods and earthworms shred plant material such as leaves into small parts called litter. They distribute the litter throughout the soil, where bacteria then complete the decomposition process (see Section 3.2.2, The Soil Bacteria and Fungi Project). If EM fields were to affect these animals adversely, there could be repercussions throughout the forest ecology.

This project includes both population and community studies, and is being conducted in Michigan. The two study sites are identified in Figure 11. One site is near the south leg of the north-south antenna, and the other is about six miles to the west. The sites are in woodlands dominated by maple trees, and are similar in most respects important to soil and litter animals.

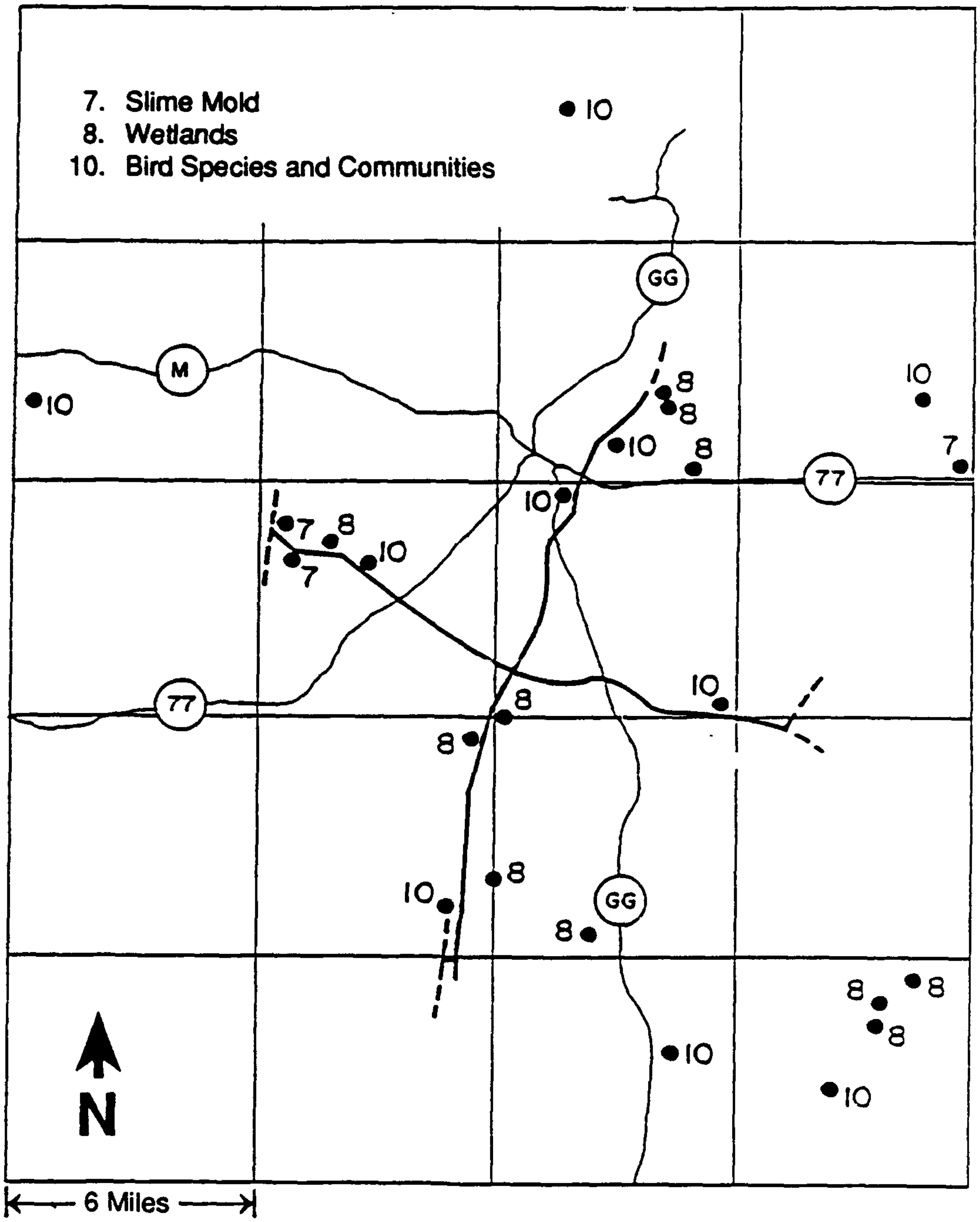


FIGURE 12. STUDY SITES FOR ECOLOGY STUDIES IN WISCONSIN.

The population studies include identifying species of arthropods that are active on the surface. Examples include springtails, mites, and ground beetles. Their day-night and seasonal activities also are being studied.

Arthropods that are active in the litter and soil also are being examined. These species are mainly mites and springtails, but they differ from the soil dwellers. The diversity of earthworm species also is being investigated.

Activities such as reproduction and development can be gleaned from studying populations (counting numbers of a species requires identifying cocoons, young, and mature animals). Thus, this project can be classified as an organism study as well as a population study. Community aspects of this study are accounted for by studying litter decay.

3.2.5 The Trees and Herbs Project

Forest vegetation produces organic compounds. The compounds eventually decompose and provide energy and nutrients to other forest biota. It is not inconceivable that trees and plants might be affected by EM fields even if forest animals were not influenced by EM field exposure. The trees and herbs project represents an attempt to determine whether the dominant forest plants in Michigan might exhibit reactions to ELF EM fields.

This project involves three study sites in a design called a split-plot investigation. Two of the sites are located near the more southern of the two east-west ELF antennas. One serves as an antenna study site and the other as a ground terminal study site. The third site is located about 35 miles to the southwest. The sites are the same as those used for the soil bacteria and fungi project (see Figure 11). Each site is split into smaller plots to accommodate several different studies.

Existing pole-size trees and red pines planted in 1984 are being monitored. Doing so accounts for young trees and near-mature trees, spanning a considerable age span for long-lived species. Short-lived vegetation is represented by studying an herb species.

Monitoring diameter growth of pole-size trees and seedlings represents a study at the organism level. Seedling height also is being monitored.

Pine is experiencing a root disease called Armillaria in many parts of the Great Lakes states. Mortality of the red pine seedlings from this root disease is being recorded. The growth studies and disease monitoring are considered to be organism studies.

The herb starflower represents the short-lived plant in this project. In this organism-level study, the timing of stem and leaf expansion and the beginning of blossoming are being followed. The numbers of buds, the numbers of flowers and fruit, and the sizes of leaves of the starflower population also are

being recorded. Some plants are grown in greenhouses and then transplanted to the study sites so that well-known specimens can be compared with plants growing naturally at the sites.

The community component of this project consists of two separate efforts. The first effort focuses on the population of an important root fungus. The fungus uses compounds produced by the trees for its growth; in return, the fungus provides the trees with water and minerals. This exchange, known as a symbiotic (i.e., favorable to both species) relationship, is known to involve biotic electrical currents, and therefore is especially pertinent since EM fields in soil produce electrical currents.

The second effort of this component examines the nutrients in oak leaves and in pine needles. The foliage is examined during its growth period, soon after leaves fall, and after leaf litter has accumulated on the ground.

3.2.6 The Native Bees Project

Bees are important members of the upland forest ecosystem. They pollinate flowering plants. Bees apparently sense the earth's magnetic field, which they seem to use for navigation. Research has shown that electric and magnetic fields produced at 60 Hz by high-voltage transmission lines can affect the behavior and survival of bees. A material called magnetite has been identified in the bodies of bees, and is believed to be involved in their sensing of magnetic fields.

Honeybees are better known biologically than most species of native bees, and would seem to be a logical species for studying whether ELF EM fields produced by the Navy's transmitters might affect pollination. However, honeybees are not found in large numbers in forest settings, because they prefer open fields and cultivated areas. Furthermore, honeybees have difficulty surviving the harsh winters in northern Wisconsin and Michigan, which would make long-term studies of stable populations difficult. Natural predators such as bears also pose another problem in attempts to study honeybees and their ecological involvement. For these reasons, native bees were selected for study.

The native bees project is being conducted at four study sites in Michigan. The sites are identified in Figure 11. Two sites are near the south leg of the north-south antenna, and two are about 10 miles west of the antenna. Most characteristics important to native bees are the same at the four sites, but 76 Hz EM field intensities at the two sites near the antenna are substantially different from the 76 Hz intensities at the distant sites.

This project was designed to investigate bees as organisms and populations and to study their activities. Reproduction and mortality studies are population observations. Nesting and activity patterns such as foraging and pollen collection are organism-level observations.

3.2.7 The Small Mammals and Nesting Birds Project

Mammals and birds use forest resources for food and shelter. Their survival could be directly at risk if they themselves are affected by ELF EM fields, or indirectly at risk if the fields affect the ecological processes that produce vegetation.

It would be virtually impossible to study large animals because they are relatively free-ranging. It would be necessary to restrain the animals in order to study the same individuals over a number of years. Restraints would not be natural, and would probably affect behavior, and possibly physiology as well. Therefore, small mammals (deermice and chipmunks) were selected as study subjects. Although free-ranging, small mammals have limited ranges and individuals can be marked and monitored easily. The selection of suitable bird species does not present problems. Two species, tree swallows and black-capped chickadees, were selected for this project.

Seven study sites are used in this project. The sites are identified in Figure 11. Numerous reasonably well-matched sites are needed so that populations are not reduced by sampling as studies continue from year to year. Three of the study sites are located along the south leg of the north-south antenna in Michigan, two are located about nine miles west of the antenna, and some studies are done at two other sites further west of the antenna.

The small mammals and nesting birds project includes studies of individuals, populations, and communities. The organism study includes embryonic development of tree swallows and measuring the metabolism of chickadees and deermice while under cold stress. The literature on EM field effects suggests that embryonic development is a critical phase during which biological effects might be produced. Biological effects also may be more likely when an animal or bird experiences more than one stress (e.g., EM field exposure and cold) simultaneously.

The population-level studies include monitoring the number of tree swallow eggs in nests, hatching success, growth after hatching, and fledging (first flight) success. These factors all affect population size. Reproduction and early growth of deermice also are being monitored.

Tree swallows, chipmunks, and deermice are being studied to determine if their homing behavior might be altered when EM fields are present. This element of the study is an organism observation. Changes in homing behavior, if they were to occur, could have profound effects on small animals and birds. For example, these animals and birds might become more likely to succumb to predators, or the care of their young might suffer.

3.2.8 The Bird Species and Communities Project

Birds are important members of forest ecosystems for several reasons. As one example, they consume insects, and in doing so control the insect population. They also have a role in dispersing

seeds, and thereby play a role in forest regeneration. There is evidence that birds may use the earth's magnetic field for navigation. There is ample reason, then, to include bird species and community studies in the ELF Ecological Monitoring Program.

These two projects involve birds that breed and reside in northern Wisconsin and Michigan, and those that migrate through those regions. Bird populations are estimated from May through September of each year by walking paths called transects through the forests. Ten transects have been established at Republic and another 10 were established at Clam Lake. Five of the transects in each region are near antennas, and five are located further from the antennas (see Figures 11 and 12).

The project designs differ from the designs of other projects. Although multiple paths are used, the paths are not matched. Matched paths cannot be used because the number of species is a study parameter, and different species have different habitat preferences. Some species prefer relatively open areas, while others prefer certain plants and trees. Therefore, each path (or transect) is analyzed independently from season to season. Since some paths are close to antennas and others are far from antennas, any influence of ELF EM fields eventually should become evident.

Data collection and analysis have been completed in Wisconsin. Studies are continuing in Michigan.

3.3 The Wetlands Ecosystem Project

Wetlands are important resources for many reasons, including the fact that they provide food and habitat for many species. Also, decomposition occurs relatively slowly in wetlands. For these reasons alone it was considered important that wetlands studies should be included in the ELF Ecological Monitoring Program.

The availability of bogs in northwestern Wisconsin made that region the preferred choice for the wetlands project. Eleven bogs at various distances and directions from the ELF antenna were selected (see Figure 12). The study design is called a gradient design. Data were not available for the years prior to construction and testing at NRTF-Clam Lake. Therefore, there was no available basis for comparing study results obtained after full-time operations commenced with conditions that existed earlier. The gradient design allowed studies to be made at numerous places where EM field intensities gradually diminished with respect to one another.

The EM field effects literature suggests that cell membranes may be involved in biological interactions with EM energy. Studies were therefore designed to emphasize plant functions involving cell processes. A species of a tree, a shrub, and an herb common to bogs were selected for monitoring. The plants were studied as organisms to detect whether changes were occurring in nutrients in plant tissues, and whether the process of producing nitrogen might be influenced. Decomposition of plant material also was studied.

A third investigation (also at the organism level) involved the physiology of plants. Stomata of plants open and close in response to environmental conditions and plant needs. By doing so, the stomata regulate water vapor and the exchange of gases between the plant leaf and the atmosphere. This mechanism is basic to the survival of plants and is a cellular-level phenomenon. The plant characteristic called stomatal resistance is related to this phenomenon and was periodically measured.

This project has been completed.

3.4 The Aquatic Ecosystem Projects

The aquatic ecosystem is made up of plants and animals. This ecosystem is not entirely independent of the forest ecosystem. For example, leaves from trees provide nutrients to aquatic inhabitants.

Both plants and animals are accounted for in a study that includes three projects. Each project concentrates on a distinct aquatic community. The communities are:

- the primary producers (algae and other plants)
- the primary and secondary consumers (insects)
- the tertiary consumers (fishes)

The aquatic ecosystem projects are being conducted at five reasonably well-matched locations on the Ford River in Michigan. The locations are identified in Figure 11.

3.4.1 The Periphyton Project

Plants and animals that attach to and live on submerged objects such as rocks collectively make up what is called the periphyton community of a river. They can show a response to perturbations at their location, and thus are appropriate biota for ecological monitoring.

Plants called diatoms dominate periphyton communities. In this project, the emphasis is at the community level. Community mass (which also is an indirect measure of population), chlorophyll, photosynthetic activity, and respiration are being monitored. These measures describe the function of the community. The makeup of the community by species also is being followed. This aspect of the study helps describe the structure of the community.

3.4.2 The Insects Project

Aquatic insects are classified as shredders, collectors, predators, and grazers. One part of this project examines insects as organisms and another part is intended to describe changes (should they occur) in the insect community. Insects are being studied because they feed off the periphyton community.

Changes in the periphyton community caused by grazing insects are being examined. The makeup of the insect community also is being monitored (a population-type study) and the mass of the most abundant species is being determined (an organism observation).

Aquatic insects break down leaves that fall into rivers. The colonization of these insects and the rate at which they process leaves are being studied. These are studies of population and community activities.

3.4.3 The Fishes Project

Fishes are called third level consumers in the aquatic ecosystem. They feed on the producers, the grazers and shredders, and other consumers. An effect on their food supply could result in an effect on the fish population.

Some species of fishes are known to have the ability to perceive very-low-intensity EM fields, and they seem to use this ability to orient themselves and to detect prey. The potential for impacts on the food supply and the EM field perception ability makes fish studies a logical part of the ELF Ecological Monitoring Program.

The fishes project is being conducted at the five sites on the Ford River in Michigan identified in Figure 11. Examinations are being conducted on individuals, on the population, and at the community level. Mobile fishes are captured by nets and weirs at the five sites, measured and weighed, then released. Other species are counted to obtain a measure of the diversity and population of the community.

Fish migration is being observed by determining the time that marked brook trout take to move from one site to another. Their direction of travel also is recorded. The age, growth, and condition of the marked fishes are studied as well. This part of the project provides information on the behavior of fishes.

3.5 The Engineering Support Project

Exposure to ELF EM fields is the principal environmental influence being investigated by this program. Other environmental factors also influence biota in their natural habitats. Investigators responsible for each project have identified those factors and monitor their values and changes. However, in order to ensure consistency in characterizing ELF EM exposures, IITRI engineers are responsible for measuring electric and magnetic fields. Field intensities are measured periodically in air and in soil at each study site used by ecological research teams.

IITRI engineers also assist ecological investigators in solving engineering problems that might be encountered. Examples include designing lightning protection for instruments used to measure air and water quality; designing fixtures for housing biota; and designing shields to reduce 60 Hz magnetic fields at field laboratories.

4. SUMMARIES OF RESULTS

Each principal investigator of an ecological monitoring project prepares an annual report of findings. These annual reports provide all important details about study sites, methods used for obtaining data, and statistical analysis and interpretation of results. The completed reports are then bound into volumes, without editing by IITRI or the Navy. The findings of all projects also are summarized each year by IITRI. This reporting procedure has been followed since the inception of the ELF Ecological Monitoring Program in 1982. Yearly summary reports are listed as References 19 through 24 and 26 through 28. Compilations of detailed findings are listed as References 25 and 29 through 36.

As might be expected when investigators have no control over natural environmental factors or the biota of interest, not every original plan or method of investigation could be followed precisely during the past 10 years. Methods that were not producing high-resolution results were either modified or discontinued. New procedures have been added to projects where necessary to maintain useful investigations. Changes to projects are described in yearly compilations. Investigations that have been consistently successful through the years are emphasized in the following summaries.

4.1 Upland Forest Ecosystem Projects

4.1.1 Soil Amoebae Project Results

Study sites for the project were selected and characterized during 1983 and 1984. Important site factors have been monitored since that time. The most important factors are temperature, moisture, and soil chemicals. Environmental conditions at the antenna site, the ground terminal site, and the distant site are reasonably well-matched.

Air temperatures at the study sites have varied by only about 5°C (9°F) for any same-month comparison from year to year since 1984. Daily temperature records are maintained between June and October. Temperature data are shown in Figure 13.

Soil moisture depends on air temperature and precipitation. With few exceptions, air temperature has been quite consistent at the study sites. With respect to precipitation, there have been only two growing seasons since 1984 when rainfall was slightly higher than normal. Five years have been drier than normal, four of them consecutive years. Precipitation data are summarized in Figure 14.

Soil moisture is measured monthly at each study site, at two depths, between June and October each year. Generally, moisture ranges between about 20% and 40% in organic soil (soil near the surface) and between 10% and 20% in mineral soil (deeper soil). Soil moisture at the sites has shown the same trends as variations in rainfall. Differences between dry years and normal years have been more apparent in soil moisture near the surface.

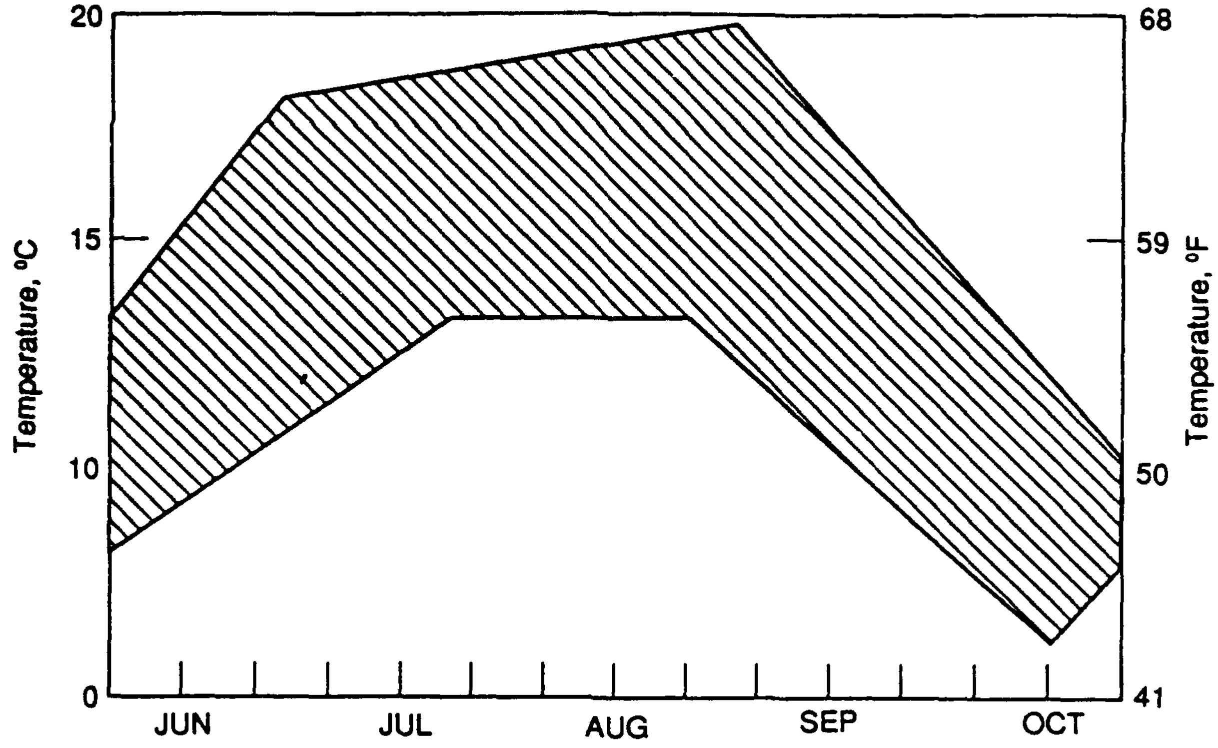


FIGURE 13. RANGE OF AIR TEMPERATURE AT IRON MOUNTAIN, MICHIGAN BETWEEN 1984 AND 1991.

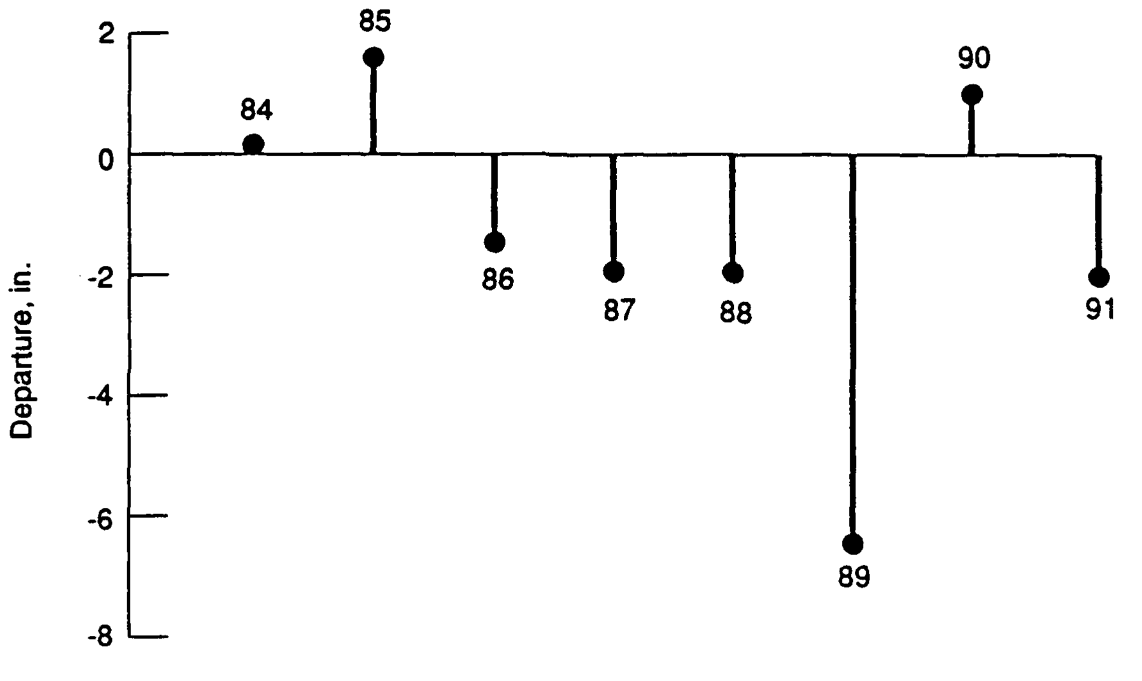


FIGURE 14. VARIATIONS IN RAINFALL AT IRON MOUNTAIN, MICHIGAN FOR JUNE-OCTOBER BETWEEN 1984 AND 1991.

FIGURE 15. EXAMPLE OF SOIL AMOEBA FOUND AT STUDY SITES.

A species of amoeba found in the acid soils at the study sites is shown in Figure 15. Eight principal species have been identified. No significant differences in species have been found between sites. Strains within one species have been investigated through genetic analysis, and no unexpected changes in strains have been observed. Changes in strains are often found when environmental stress occurs.

Total amoebae at the three study sites do not differ. Population sizes are higher in organic soil than in deeper mineral soil. The numbers of amoebae have varied from year to year, and correlate with soil moisture and precipitation. Community numbers approach millions per gram of soil in normal years,

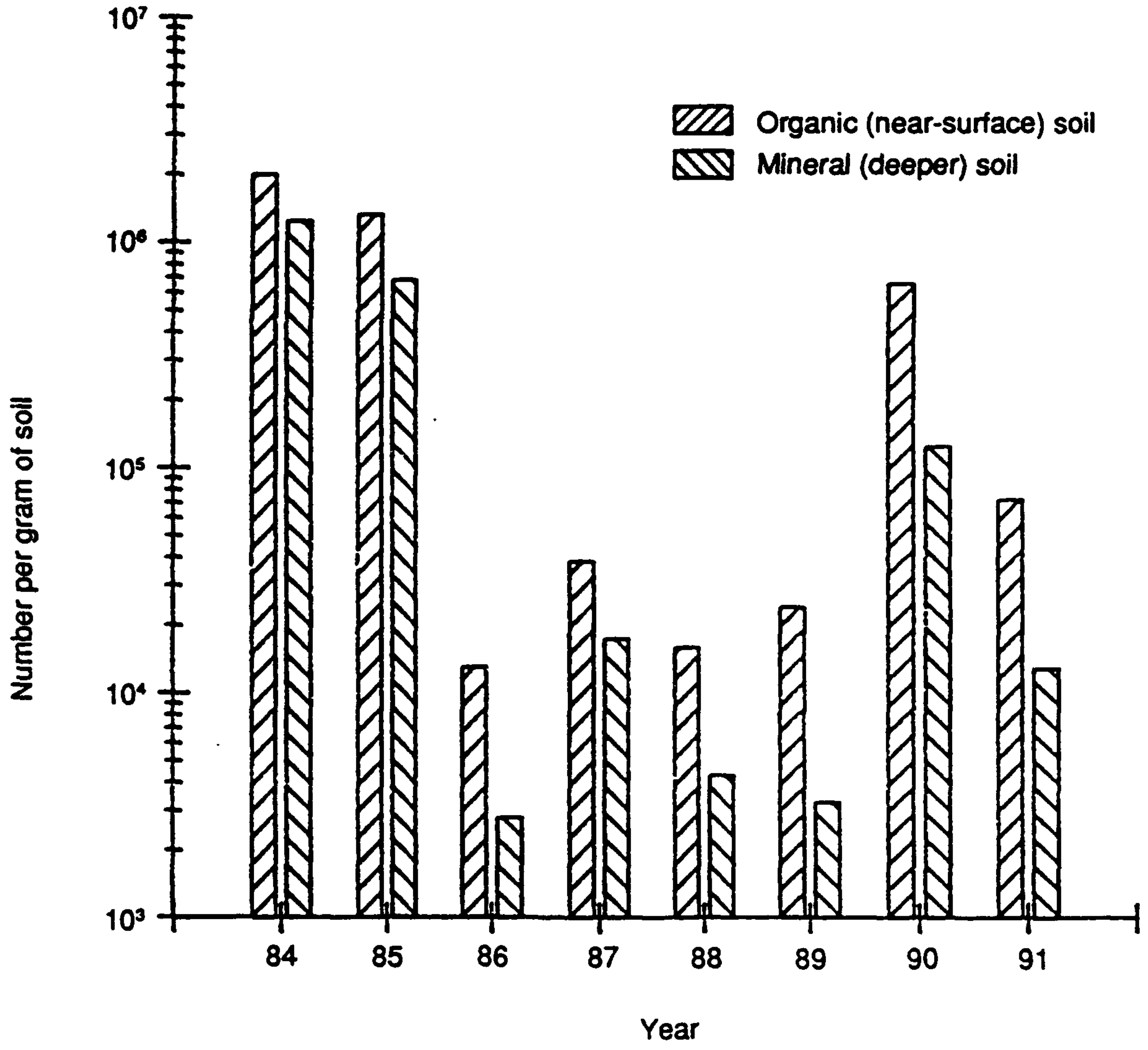


FIGURE 16. AVERAGE YEARLY MAXIMUM SOIL AMOEBAE POPULATIONS AT THREE STUDY SITES.

but drop as low as thousands per gram in dry years. The observed variations are shown in Figure 16. Populations build up between June and August, then drop again in September and October.

The productivity of amoebae could be affected if their food supply were altered or if population growth changed. Productivity has been monitored in two ways: the ratio of active to dormant organisms is calculated, and growth in buried chambers is observed. The active/dormant ratio has followed trends in soil moisture, with no significant differences between the three study sites. There are fewer active organisms during dry months and dry years.

The buried chambers provide information about population growth, feeding activity, and generation times. Chambers are used because otherwise it would be virtually impossible to determine populations of all species (one species can be isolated and monitored in the chambers). Interactions with other soil organisms also can be avoided using this technique. Results have been obtained only since 1989, but through 1991 there appear to be no differences in population growth, generation time, or feeding activity between the three study sites.

4.1.2 Soil Bacteria and Fungi Project Results

Armillaria root disease is a soil fungi phenomenon that is being studied. The other project work involves the decomposition of plant matter and bacterial activity near red pine seedlings.

4.1.2.1 Armillaria Root Disease. Armillaria root disease was first observed in 1986 in the red pine seedling plots established for this program. The disease results from white rot fungi that colonize both through the air and soil, then decay woody material, stumps, and root systems. Infection occurs through recolonization as one food base is depleted, or as roots contact infected food bases. The species are very large and long-lived. An example is shown in Figure 17.

Armillaria root disease epidemics in the Great Lakes states seem to peak after about 10 years. The disease has killed from 1% to 33% of the red pine seedlings at the various ecological study plots in about five years. The epidemic at the study plots is expected to continue because there is an adequate food base for the disease. It has been found elsewhere that the disease especially attacks stressed plants, and this study element is therefore important.

The epidemic is being examined by plotting its progress at 12 study plots at each of three study sites. Although three species of Armillaria have been identified, only one attacks red pine. Individual organisms may differ genetically within that species (similar organisms are called clones). Each clone operates within an identifiable area.

The disease has been plotted and its progress has been analyzed at the study sites near the antenna, at the site near a ground terminal, and at the distant site where 76 Hz EM field intensities represent no exposure. The disease is most prevalent at the ground terminal site and least prevalent at

FIGURE 17. EXAMPLE OF ARMILLARIA ROOT DISEASE ON A RED PINE SEEDLING.

the distant site. Data analysis cannot be completed until several more years of observations are obtained. The analysis will concentrate on finding whether the disease can be related to precipitation, red pine seedling height, stump population, or 76 Hz EM field intensities in soil.

4.1.2.2 Litter Decomposition. Leaf litter that falls from trees each autumn is decomposed primarily by microorganisms. Nutrients in the litter are transformed into forms that can be used by plant roots. The nutrients are released by the microorganisms at rates that are affected by environmental factors.

Leaf litter from red oak and red maple, and needles from red pine, are collected ever' autumn far from the ELF antenna. Packs of litter and individual leaves and needles are dried and weighed. Their nutrient content also is determined. The samples are then placed at the study sites in December.

During the following year, litter samples are retrieved monthly from May until November. Each sample is weighed to determine its remaining mass. Weight differences are a measure of the

decomposition that has occurred. Comparable data have been collected for seven years. The first two years represent time prior to operation of the ELF transmitting antenna, three years represent time during which the antenna was operated only part-time for engineering tests, and the last two years are years in which the antenna has been operated full-time.

Typically, pine and oak litter lose about 15% to 30% of their dry weight during the first year. Maple litter data have been more variable, with losses ranging from about 30% to 60% during the first year. Differences between sites and between years of about 3% to 4% can be detected for pine, about 7% tor oak, and about 8% to 11% for maple litter.

Some of the differences that have been found in decomposition from year to year and between sites are listed in Table 4. Ten environmental factors have been related to the differences. Examples include rainfall, air and soil temperature degree days, and nutrient content. Electromagnetic field intensity also is being examined as a factor, but only two years of full-time ELF system operations are insufficient to form conclusions about whether EM fields affect litter decomposition.

TABLE 4. EXAMPLES OF YEAR-TO-YEAR DIFFERENCES IN OAK LEAF DECOMPOSITION AT THREE STUDY SITES

	Mean Percentage of Dry Weight Remaining					
	(May) Measurement Site			(November) Measurement Site		
Year	Antenna	Ground	Distant	Antenna	Ground	Distant
1985	92	92	95	74	68	69
1986	93	93	94	69	67	68
1987	94	92	95	71	74	73
1988	91	92	95	67	66	68
1989	92	91	92	69	67	68
1990	97	96	97	74	75	72
1991	Data Analysis Not Yet Complete					

Note: 1985-1986 ELF antenna being built
1987-1989 ELF antenna test years
1990-1991 Full-time ELF antenna operations

4.1.2.3 Red Pine Fine Root Bacteria. Organisms called streptomycetes are found on the fine roots of red pine seedlings. These organisms are involved in the production of antibiotics, vitamins, hormones, and other compounds. Streptomycete populations do not undergo large population changes in stable ecosystems.

Samples of fine roots of red pine seedlings have been collected from the three study sites (antenna, ground terminal, distant site) once each month from May through October since 1985. The streptomycete populations on each sample are determined after 14 days of incubation in the laboratory. Several different strains have been found, and each strain is classified (each strain is assigned a letter by scientists).

Total numbers of the bacteria tend to be about 300,000 per gram of soil in May, reach a peak of about 500,000 per gram in June or July, and then drop to about 100,000 per gram by October. Typically, the number of strains in each sample does not exceed four or five.

Differences in numbers of bacteria have been observed between study sites and from year to year. The differences have not been consistent; that is, no one study site has shown a higher or lower population than the other sites for every year. The number of strains has remained relatively consistent.

The variations between sites and from year to year are detectable if they are in the order of about 10% to 20%. To date, the variations have been fully explained by environmental and procedural factors. The former include soil pH, air temperature degree days, soil temperature degree days, amount of rainfall, and number of days of rain. The procedural factor is handling of samples. Electromagnetic field exposure does not appear to be an influence, but only one year of EM exposure data has been accounted for, since 1991 data analysis is not yet complete.

4.1.3 Slime Mold Project Results

Goodman and his associates at the University of Wisconsin Parkside campus had reported in the 1970s that slime mold was affected by EM field exposure.[37, 38] The investigators reported that cell division was delayed and respiration was depressed if the organisms were exposed for at least six months to EM field intensities that were 10 times higher than produced by the ELF transmitting antenna in Wisconsin. The effects observed in the laboratory were reversed a few weeks after EM field exposure was removed.

An EM effect on cell division or respiration in slime mold would indicate possible effects to other organisms. Therefore, a slime mold study was included in the ELF Ecological Monitoring Program. The study commenced in 1982 at three sites in Wisconsin (see Figure 12), and was completed in 1987.[39]

Slime mold cultures were placed in buried chambers at the three study sites. The chambers were used to isolate the cultures from other soil organisms and to protect them from foraging wildlife. The chambers were placed in the field in May, periodically re-cultured, and removed in October of each year during 1985, 1986, and 1987.

Slime mold cultures also were grown in the Parkside laboratory. The temperature at Clam Lake was duplicated, but field exposures higher than at Clam Lake were used (see Table 5). The cultures grown at Clam Lake could not be handled precisely like the cultures studied in the laboratory in the

1970s, but the cultures grown in the laboratory in this project were handled like those in the experiments of the 1970s. Duplicating the laboratory handling was important for determining whether handling of field-grown cultures would confound data comparisons during the present project.

4.1.3.1 Electromagnetic Field Exposures. Electromagnetic field intensities were measured at the three study sites at Clam Lake and at the Parkside laboratory. Intensities were measured at 76 Hz (the Navy ELF transmitting frequency) and at 60 Hz (fields produced by power lines and appliances). The 76 Hz fields were produced in the laboratory with special equipment.

Electric fields in soil produce currents that depend on the characteristics of the soil. It is not known whether electric field intensity is more important than current density, or vice versa. The slime mold placed in chambers required a material called agar for nourishment. Agar has different characteristics than Clam Lake soil, so electric fields in some chambers were manipulated to produce the same current density as in soil outside the chambers. In others, the electric field intensity was maintained the same as in soil. Similar adjustments were made in the Parkside laboratory. Magnetic fields are not influenced by soil characteristics.

The EM field intensity exposure conditions used from 1984 through 1987 are summarized in Table 5.[39-41] The 60 Hz electric and magnetic fields at the Clam Lake sites are comparable and much lower than the 76 Hz field intensities, a desirable condition. The 76 Hz field intensities at the distant site also are very low, another desirable condition. Laboratory field intensities approximate those used in the 1970s.

4.1.3.2 Respiration. A small sample of each culture at the three Clam Lake study sites was removed once a week from May through September of each year and transported to the Parkside laboratory for measuring respiration. The findings were as follows:

(a) respiration was significantly lower in the samples from the distant site than in the samples from the antenna and ground terminal sites in 1985;

(b) respiration was significantly different among the samples from the three study sites in 1986; and

(c) respiration was essentially the same among the samples from the three study sites in 1987.

There were no consistent trends observed in respiration between samples taken from chambers in which electric fields were controlled and chambers in which currents in agar were not controlled. There also were no consistent trends in results obtained from one year to the next.

TABLE 5. SUMMARY OF ELECTROMAGNETIC FIELD EXPOSURES FOR SLIME MOLD STUDIES

Study Site	76 Hz Electric Field, V/m	76 Hz Magnetic Flux Density, Gauss
Antenna and Ground Terminals	0.2 to 1.5	0.003 to 0.040
Laboratory	0.8 to 1.0	0.070 to 2.0
Distant Site	0.001	0.00001

Respiration differed very little among samples taken from laboratory cultures. No distinctions of significance could be made from samples exposed only to 60 Hz fields versus samples exposed to 76 Hz fields, or from samples with controlled field intensities versus samples with controlled current densities. Respiration rates were in approximately the same range for laboratory samples as for Clam Lake samples.

The investigators concluded that experimental factors other than ELF EM field exposures adequately explained differences in observed results. The lack of consistency in observed differences among study sites and years especially appeared to support the conclusion that the relatively weak 76 Hz field intensities produced by the NRTF-Clam Lake had no effect on slime molds during their approximately five-month-long active period per year.

4.1.3.3 ATP Production. Slime molds, like all organisms, produce a substance called ATP (adenosine triphosphate) when they consume oxygen. This protein-like substance is a source of energy for the organism. The amount of ATP produced by the samples used in this project was extracted and measured when respiration was determined.

The ATP results were much like the respiration results. Since there is a physiological relationship between the two processes, these results were expected, and add credence to the conclusion that the NRTF-Clam Lake is an unlikely influence on slime mold physiology.

4.1.4 Soil and Litter Animals Project Results

Populations, the characteristics of populations (such as age groups), and the community activity of decomposing leaf litter have been monitored for soil animals since 1984. Some observations were not recorded until 1985, because several study methods were not perfected until then.

Important environmental factors are monitored periodically at the two study sites identified in Figure 11. These include air temperature, rainfall, and soil moisture, all of which affect animals that live in vegetative litter and in soil. Differences in these factors have been minor between the two sites. However, precipitation (and therefore soil moisture) has been low during most years since 1984, and has influenced soil and litter animal populations.

4.1.4.1 Soil and Litter Animal Populations. Soil and litter animal populations change as forests age and change. Some species become more abundant and others become less abundant. Variations in weather from one year to the next also influence populations; thus, it is not surprising that changes in populations have been observed at the two soil and litter animal study sites since 1984.

Examples of soil and litter animal species are shown in Figure 18. Examples of changes that have been observed in the populations of three species are shown in Figure 19. It may be significant that population trends were consistent from 1984 through 1988 (prior to ELF transmitter operations) between the two sites. One species of soil animal and one of litter animal were most abundant at the distant site. Another species of litter animal was more abundant at the test site.

Population trends for one species changed after ELF transmitter tests started in 1988 (the litter species *O. hexfasciata*). The species became more abundant at the distant site. Additionally, populations of another litter species have been increasing at the antenna site and diminishing at the distant site since 1988.

Data for 1991 have not yet been fully analyzed. Those results are important for determining whether the reversal of population trends observed since 1988 for the two species of litter animals has continued. If so, analyses will focus on the possibility that EM field exposure may affect soil and litter animal populations.

FIGURE 18. EXAMPLES OF SOIL AND LITTER ANIMALS.

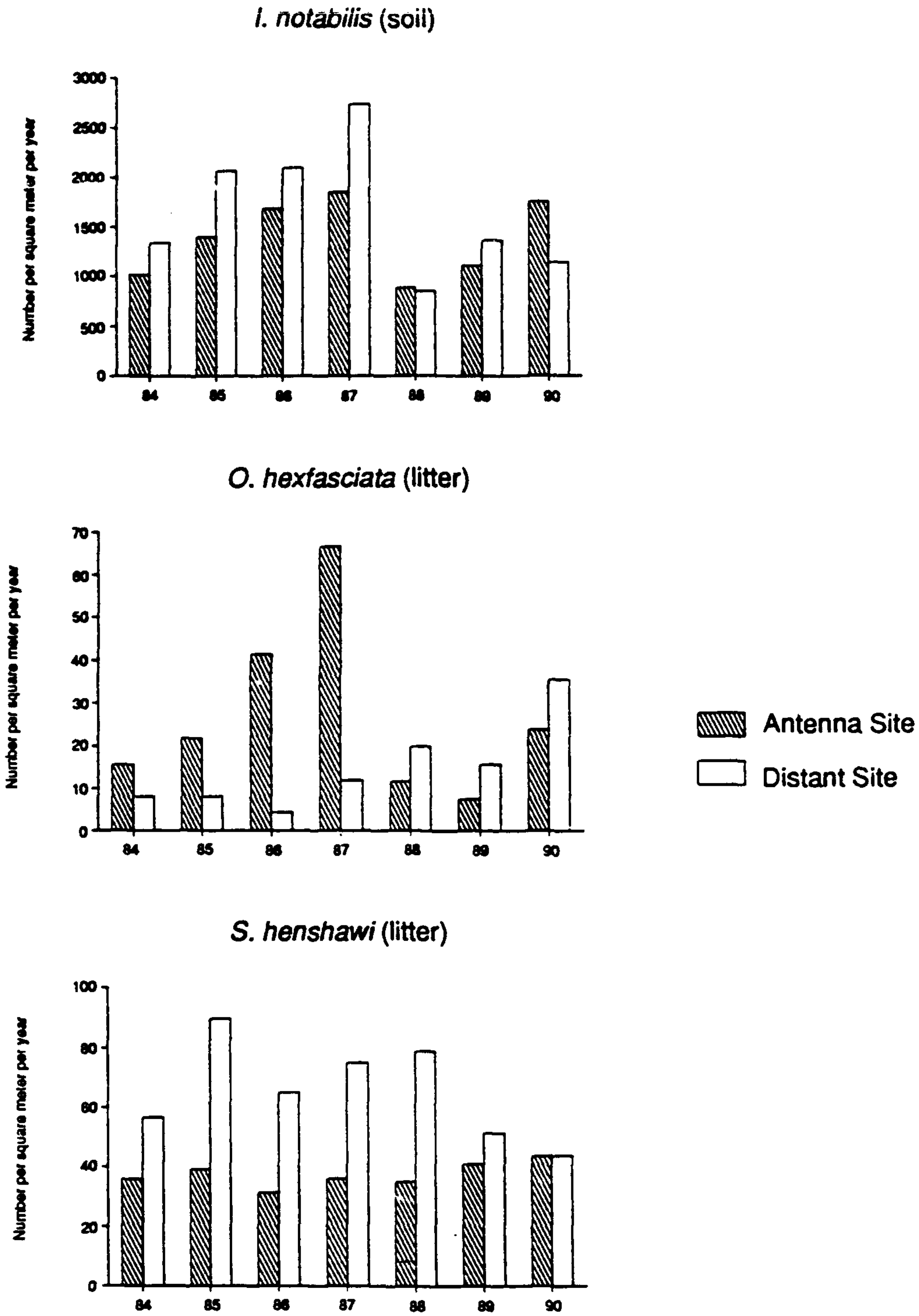


FIGURE 19. POPULATION DIFFERENCES OBSERVED FOR THREE SPECIES OF SOIL AND LITTER ANIMALS SINCE 1984.

4.1.4.2 Surface-Active Animals. Eleven species of arthropods that are active on the surface are being studied. Populations are sampled by periodically trapping and counting the animals, and differentiating between males and females and mature and immature animals. Activity patterns are monitored by trapping during the day and at night. Seasonal changes in activity also can be observed in the trapping data. An example of a surface animal pit trap is shown in Figure 20.

A typical example of findings is shown in Figure 21. Large year-to-year changes in populations are apparent, and can be related to natural environmental factors. Populations build up from May to midsummer, and then decrease consistently every year. No significant unexplained differences in study parameters have occurred between the two sites since 1985.

4.1.4.3 Earthworm Populations. A large amount of data about earthworms at the two study sites has been accumulated, but the interpretation of results is not complete. One of the reasons for the analytical delay is that species composition differs somewhat between the two sites, and species abundance continues to change from year to year at the sites. Analysis of results must therefore proceed cautiously. Some trends in data are nevertheless apparent.

Even though earthworm species differed, the diversity of species between the two sites was comparable from 1984 until 1987. Since then, the diversity has increased slowly at the distant site and decreased slowly at the antenna site. The increase at the distant site has been related to increasing

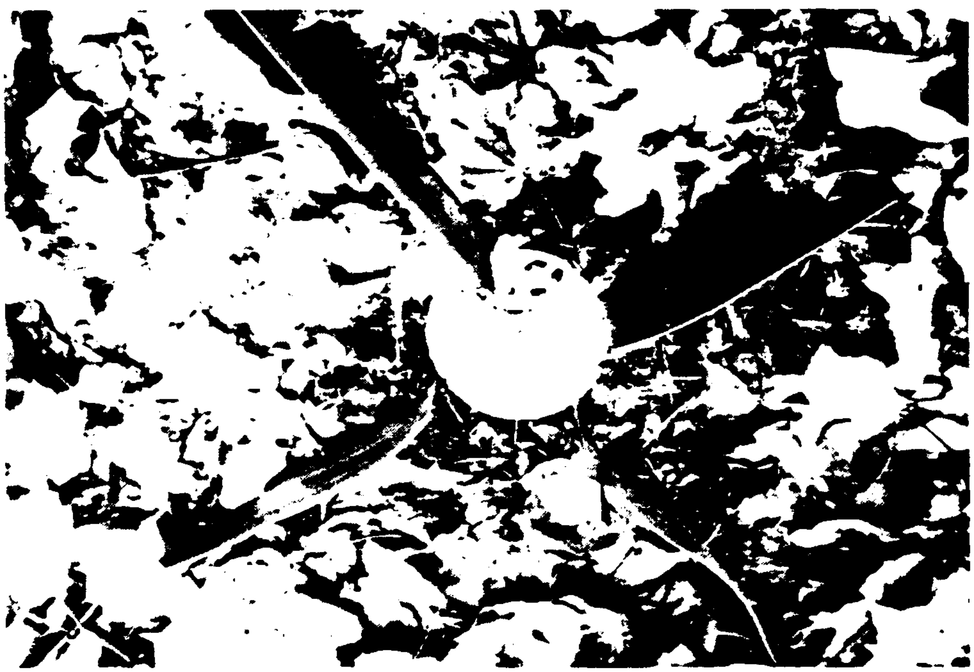


FIGURE 20. PIT TRAPS ARE USED TO COLLECT SURFACE-ACTIVE SOIL ANIMALS.

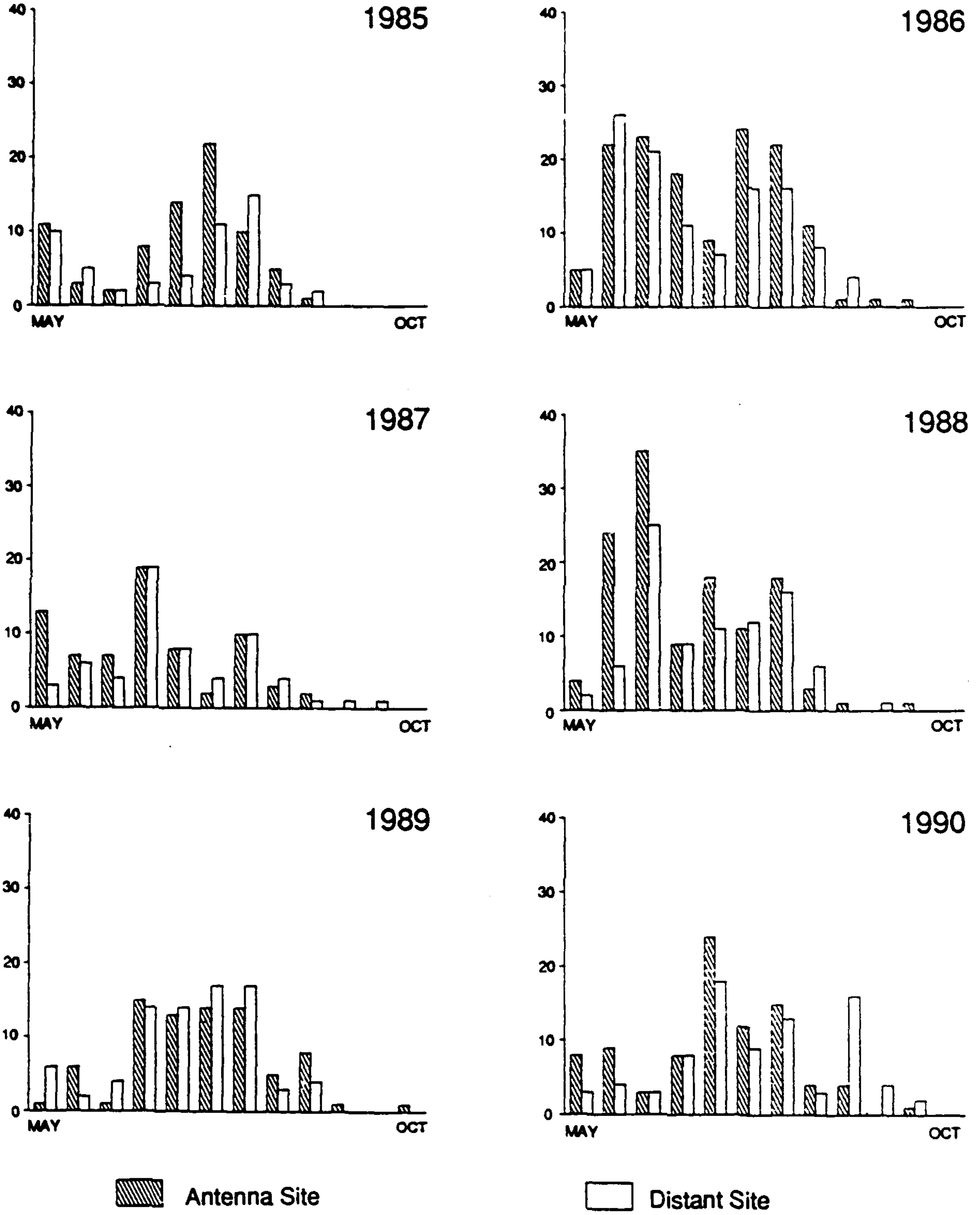


FIGURE 21. TRENDS IN THE POPULATION OF A SURFACE-ACTIVE ARTHROPOD (HARPALUS FULIGINOSUS) SINCE 1985.

numbers of three species. At the antenna site, on the other hand, one species has been especially dominant, and its population is increasing, while the populations of the other two common species at the site have been influenced by drought years.

The trends in the population data are shown in Figures 22, 23, and 24. Since changes have been apparent since 1984, there is as yet no evidence that EM field exposure is involved in species diversity or density at the two sites. One cannot conclude that the opposite proposition is true, however; data must be collected for several more years before definitive statements can be safely made.

4.1.4.4 Earthworm Reproduction. Prior to the start of ELF transmitter tests in 1989, the soil and litter animals project investigators observed a consistent relationship between cocoon densities and the percentage of reproductive animals in the following years. The relationship was observed for one species at the antenna site and for another at the distant site.

The consistent relationship virtually disappeared after 1988 at the antenna study site, and corresponds to the start of full-time ELF transmitter operations. As noted earlier, however, population

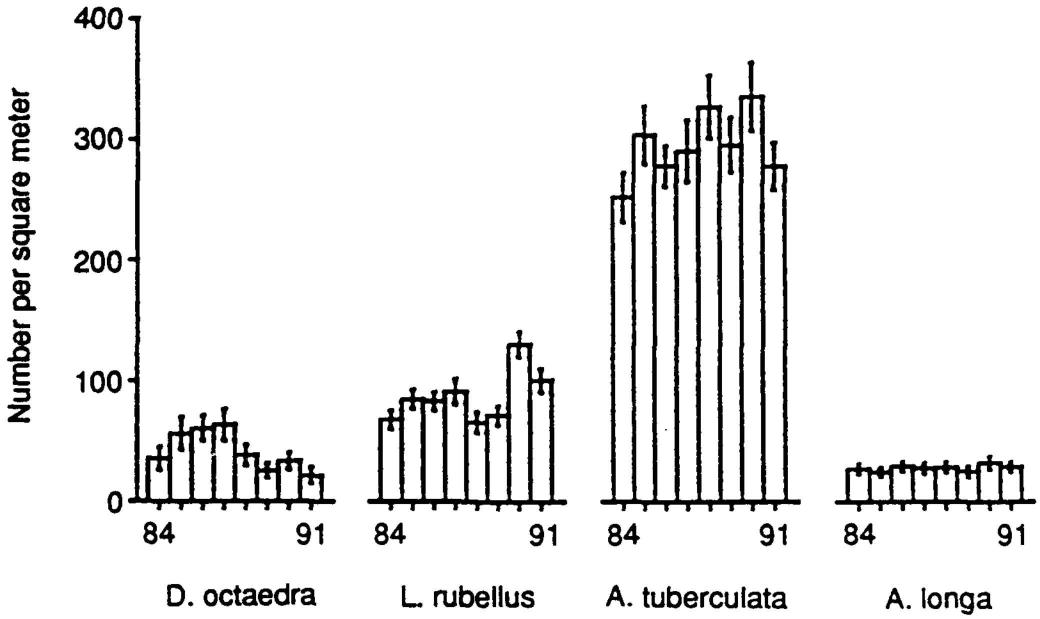


FIGURE 22. EARTHWORM SPECIES DENSITY AT THE ANTENNA STUDY SITE.

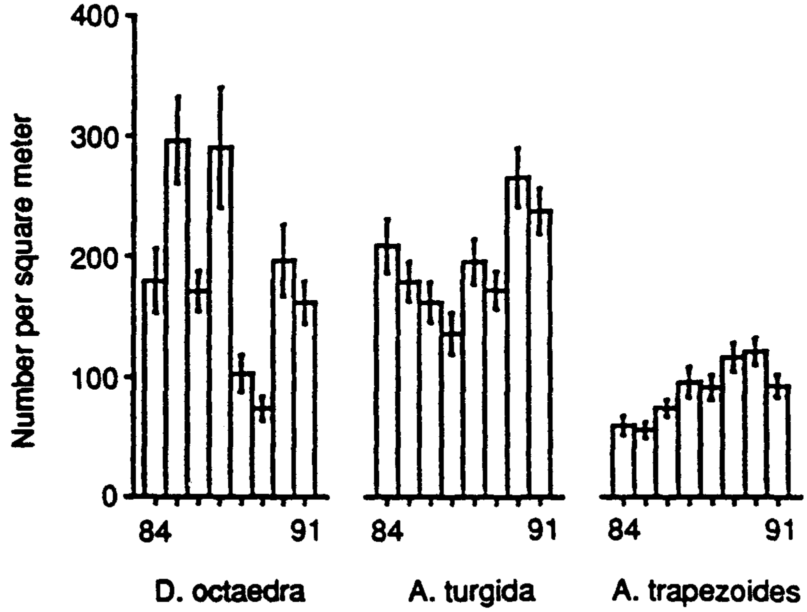


FIGURE 23. EARTHWORM SPECIES DENSITY AT THE DISTANT STUDY SITE.

trends at the study sites also have changed, as have important environmental factors. Possible causes have been investigated.

One would expect certain changes in the earthworm community to occur as a result of weather patterns that have been experienced since 1988. Summers have been hotter and drier, so earthworms would be expected to burrow deeper into the soil. That behavior change has not been evident in the data. Likewise, the percentages of adults in the population have not changed much.

The number of reproductive animals of the dominant species at the antenna study site has changed since 1988, but the number of cocoons has maintained a consistent relationship with the number of reproduction-age animals. In other words, some factor or combination of factors has seemed to affect reproduction-age earthworms, but not reproduction rates.

Several possibilities are being investigated to explain what has happened to the earthworm population since 1988. Perhaps reproduction-age animals remain capable of reproduction for shorter times. Another possibility is that the rate of cocoon production might have dropped since the start of ELF transmitter operations. A new study has been initiated to investigate these possibilities.

Some of the dominant species at the antenna site are being collected and isolated in mesh bags. These bags are filled with soil from the antenna site, then some bags are placed at the antenna site and

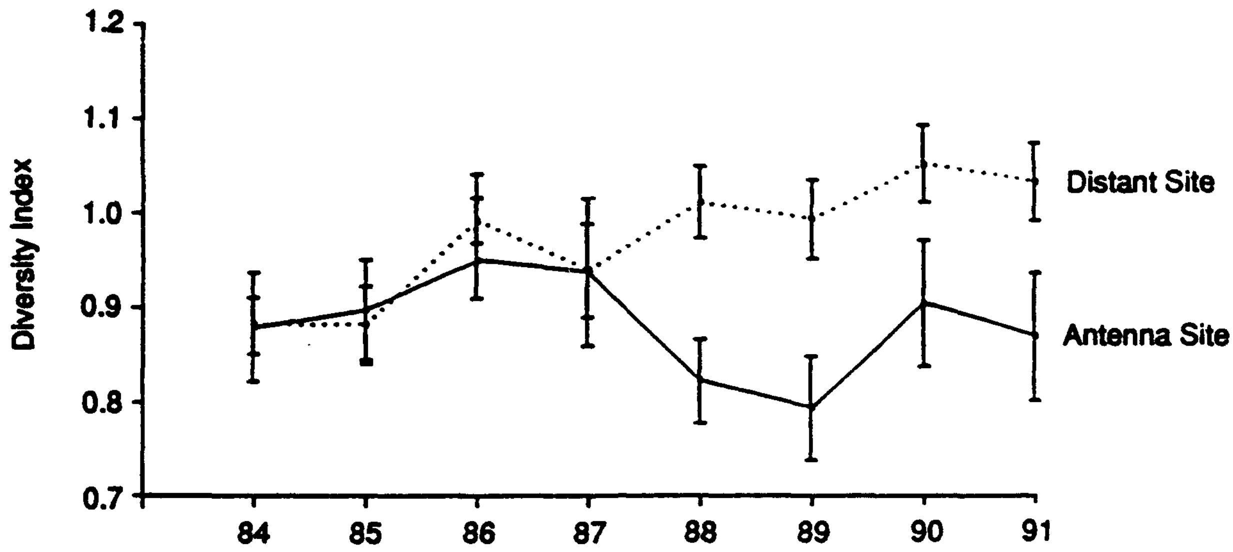


FIGURE 24. CHANGES IN EARTHWORM SPECIES DIVERSITY AT THE TWO STUDY SITES SINCE 1984.

others are placed at the distant site. The bags are periodically retrieved to monitor earthworm development and reproductive activity.

Data are available for only one season, so conclusions are not yet possible. The study method appears to be useful, and the isolation study will continue. During the first season, less than 30% of the animals isolated at the antenna site appeared to show reproductive activity. The percentage at the distant site was about 67%.

The change observed in the population characteristics of the most dominant earthworm species at the antenna study site (the species *A. tuberculata*, see Figure 22) makes it important to examine whether the next dominant species at the site (*L. rubellus*) also has experienced change since 1988. Unlike *tuberculata*, *rubellus* almost never burrows deep into the soil, and smaller immature members are found in leaf litter.

To date, no significant changes have been observed in the near-surface *rubellus*: they remain near or on the surface, and their reproduction does not appear to have been affected since 1988. Firm conclusions are not now justified, however.

4.1.4.5 Litter Decomposition. The decomposition of leaf litter at the two earthworm study sites has been studied by periodically weighing litter remaining in mesh bags like those shown in Figure 25. Decomposition rates have been comparable at the two sites, and can be related to the species and their abundance at the sites. About 90% of the differences in decomposition rates observed between sites and

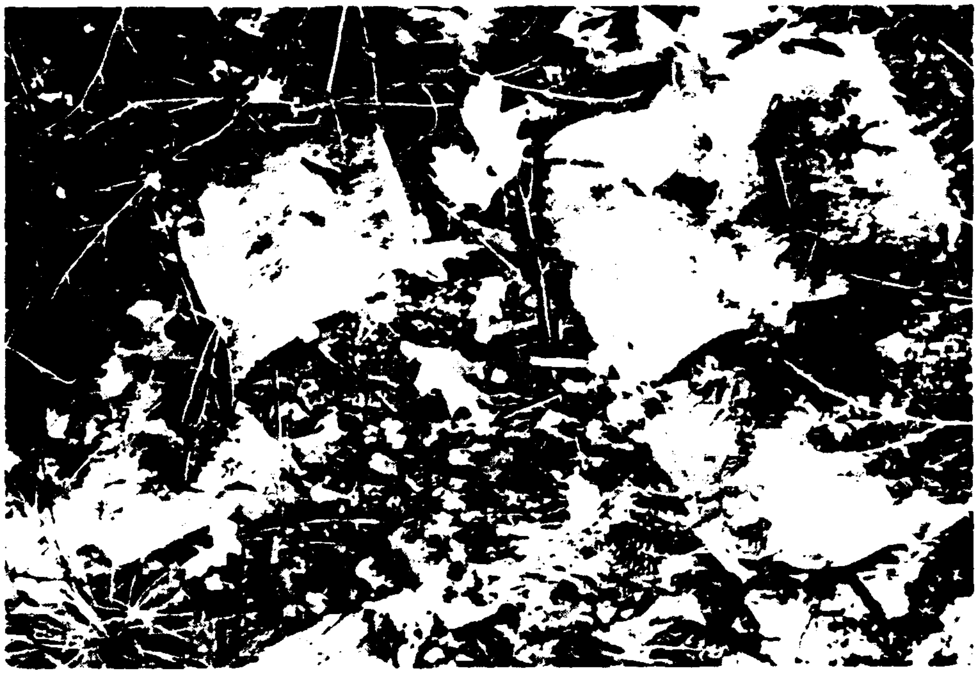


FIGURE 25. LEAF LITTER DECOMPOSITION BY EARTHWORMS IS MONITORED BY WEIGHING LITTER REMAINING IN MESH BAGS.

between years have been related statistically to earthworm species diversity and density. Statistical analyses have not identified EM field exposure as a factor in observed results.

4.1.5 Trees and Herbs Project Results

Seven distinct studies have been conducted every year in this project, and variations in natural environmental factors that influence plants also are monitored.

4.1.5.1 Natural Environmental Variables. Air temperature and rainfall, soil temperature and moisture, relative humidity, and sunlight differ only slightly among the three sites. Variables that influence biological parameters have been identified and are used to explain differences in plant growth and physiology among the sites. Some variables conceivably could be affected by EM fields. For example, if trees grew faster near the antenna than at the distant site, one might expect soil moisture and sunlight reaching the surface to be lower at the distant site.

No relationships have been found to date that ELF EM fields have an influence on natural environmental variations recorded at the study sites. This is illustrated by the data shown in Figure 26. The scatter shows that air temperature at the sites is independent of 76 Hz electric field intensity. The data would be clustered if a relationship existed.

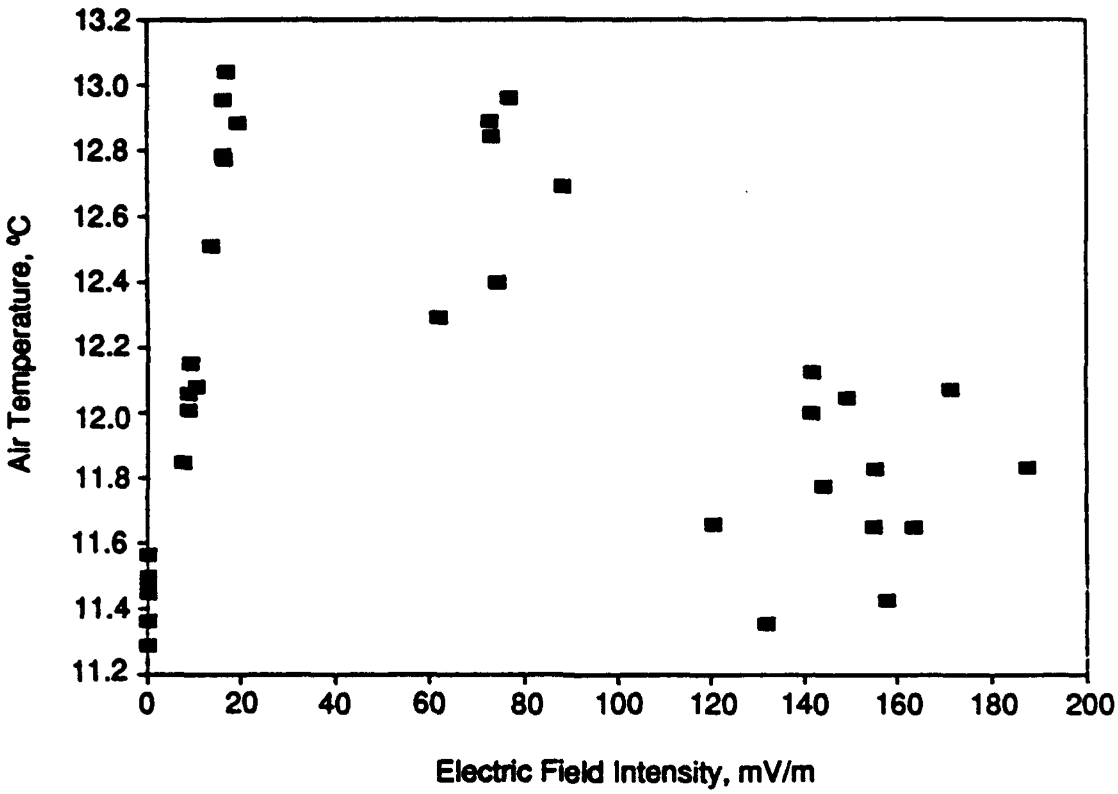


FIGURE 26. SCATTER IN DATA SHOWS THAT 76 Hz EM FIELDS DO NOT INFLUENCE NATURAL ENVIRONMENTAL FACTORS AT THE TREE GROWTH STUDY SITES.

Soil nutrients available to and needed by plants also are monitored at the study sites. Nutrient values such as calcium differ somewhat among the sites, and within each site as well. The variations are not statistically significant and do not represent difficulties in analyzing and interpreting study results.

Nitrogen is one of the most important nutrients for plants. Nitrogen in the organic state is converted to the inorganic state by plants through processes called ammonification and nitrification. These processes have been monitored by analyzing soil samples from the antenna study site and the distant site since 1990. Differences have been found between the sites, and the mineralization process also changes seasonally. The data are useful for explaining differences in plant growth observed between the sites because the processes are influenced by soil types and microbial populations.

4.1.5.2 Hardwood Tree Growth. Hardwood tree study sites are located near the antenna and at the distant site identified in Figure 11. Several growth factors are monitored to study the growth of mature trees, including the following:

- tree diameter
- tree height

- tree species
- mortality

Tree diameter measurements are the most precise. Devices called dendrometers are permanently attached to trees and can measure diameter growth as small as 0.003 in. (0.008 cm). Figure 27 shows an investigator reading a dendrometer.

The study sites are dominated by red oak, paper birch, aspen, and red maple. Tree diameter growth has been comparable at the two study sites since 1984. Small differences observed between sites have been attributed primarily to soil differences. Small differences from year to year are related to rainfall. There has been no evidence to date that ELF EM fields are *affecting* tree diameter growth.

Actual diameter growth for the four species has been compared with expected growth. Aspen and birch, which do not live as long as oak and maple, have been growing somewhat more slowly than

FIGURE 27. TREE GROWTH IS MONITORED BY MEASURING TREE DIAMETER GROWTH WITH PERMANENTLY INSTALLED DENDROMETER BANDS.

expected. The slower growth appears to be related to the warmer-than-usual air temperatures and lower-than-normal soil moisture in recent years. Birch also are suffering higher mortality than is usually experienced. These trends also have been observed elsewhere in the region and seem to be attributable to natural stresses. Additionally, paper birch mortality has increased because of an infestation of the bronze birch borer throughout the Great Lakes region.

Full-time operation of the Republic ELF transmitter facility only commenced in late 1989. Data are not yet sufficient to determine whether ELF EM fields might be affecting the growth of mature hardwoods.

4.1.5.3 Hardwood Leaf Litter Production. Fallen leaves are gathered for analysis throughout the summer and autumn (but primarily in the autumn) at the antenna site and at distant sites. The leaves are weighed and measured and their nutrient concentrations are determined. The study is important because leaves are a principal source for nutrients in the soil.

Considerable differences were found in leaf litter between the two study sites before the ELF transmitter was activated, and those differences have continued since transmitter operations commenced. The differences are largely accounted for by three factors: differences in species diversity at the study sites; variations in air temperatures from year to year; and variations in soil temperatures from year to year. Exposure to ELF EM fields at the antenna study site apparently is not a factor.

4.1.5.4 Red Pine Growth. Young trees may be affected by environmental stresses more than mature trees are. In 1984, plantations of red pine seedlings were established at cleared plots near the antenna, near a ground terminal, and at the distant study site so that seedling growth could be monitored (see Figure 11).

Data are recorded for air and soil environmental variables and for plant competition factors to help interpret study results. The latter include the presence of plants close to individual trees (other plants compete for soil nutrients) and soil compaction.

Diameter and height are measured weekly to analyze growth rates and total seasonal growth. The sizes of pine buds are measured as an indication of vigor. Weekly growth at the three sites tends to be slightly higher than expected during the spring, but somewhat slower than expected during the summer. Early season growth depends on soil conditions that are affected by climate during the previous year. Soil conditions during the current summer are influenced more by current climate. As a result, current climate has more of an effect on summer growth.

Growth rates are essentially the same at all three study sites. An example of weekly growth rates for 1990 at the ground terminal site is shown in Figure 28.

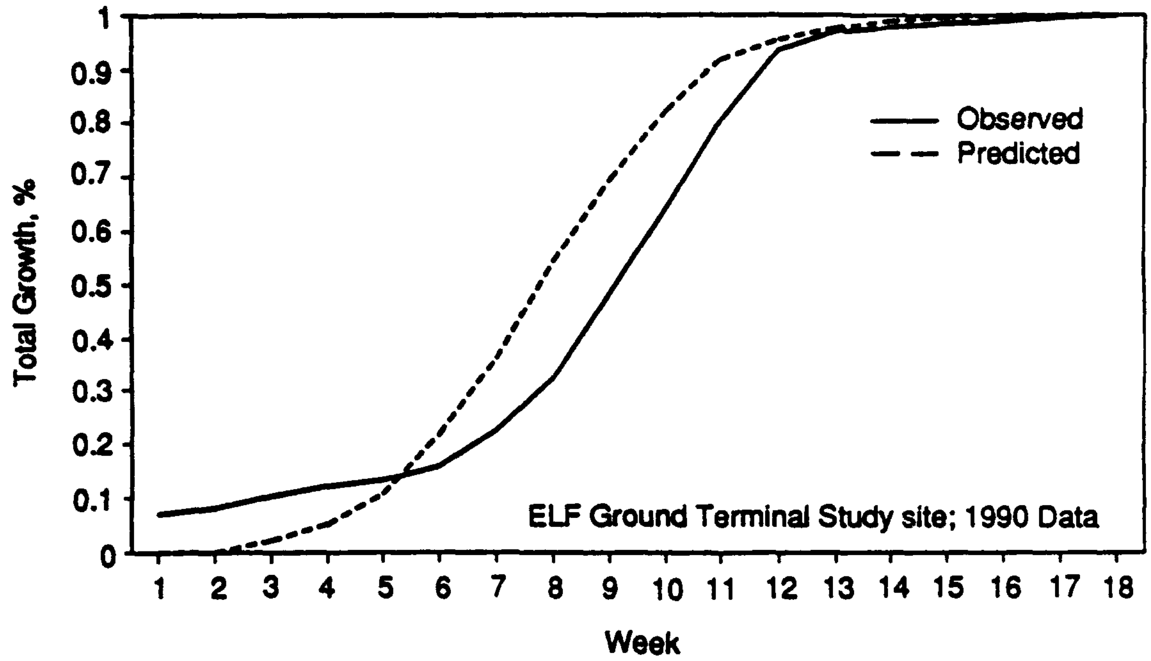


FIGURE 28. PINE TREE WEEKLY GROWTH IS FASTER THAN EXPECTED IN SPRING, SLOWER THAN EXPECTED IN SUMMER, AT ALL THREE STUDY SITES.

Diameter growth at the three study sites was nearly the same between 1984 and 1988. There has been somewhat less diameter growth in the trees at the ground terminal sites since 1988 compared to the growth recorded at the other two sites.

As measured by height, the trees have grown fastest at the distant site and slowest at the ground terminal site since 1984. As Figure 29 shows, there is some indication that differences in tree height among the three sites have become larger in recent years.

Analysis of the height data has shown that differences in physical, chemical, and other environmental factors among the sites during the previous year explain some, but not all, of the observed height differences. This interpretation only applies for 1984 through 1990, since 1991 data have not been fully analyzed. With only one full growing season corresponding to full-time ELF transmitter operations, conclusions about ELF EM field effects on red pine growth are not warranted at present.

4.1.5.5 Pine Tree Water Stress. Pine trees receive most of the water they need through their root systems. Plant moisture is measured as leaf water potential, and such measurements are made on selected pine needles at each of the three study sites. Leaf water potential could be useful in explaining some of the differences in growth observed in this project.

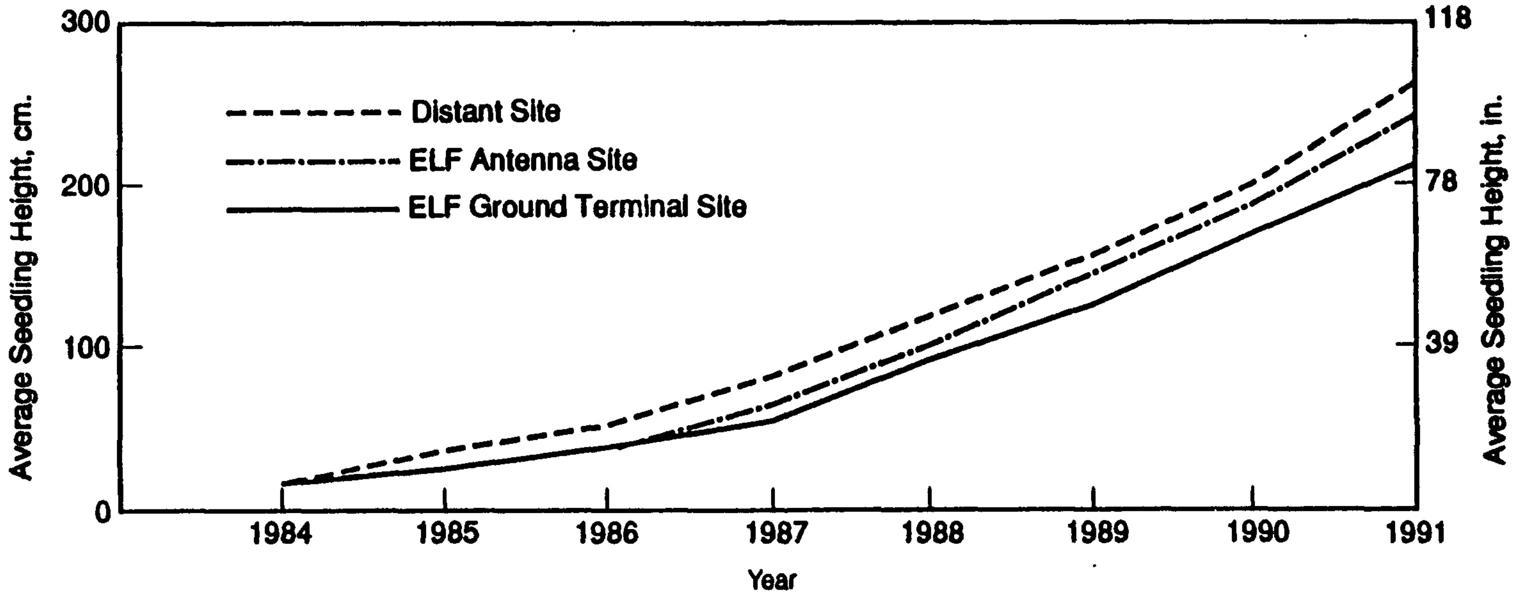


FIGURE 29. PINE TREE GROWTH HAS BEEN FASTEST AT THE DISTANT SITE AND SLOWEST AT THE ELF GROUND TERMINAL SITE.

Data collected since 1986 suggest that pine trees at the study sites are not suffering from water stress. Variations in data have been observed at all sites and for all years. Initiating ELF transmitter operations seems not to have affected plant moisture.

4.1.5.6 Pine Tree Nutrients. There should be a consistent relationship between nutrient concentrations in soil and nutrients in plant tissues if plants are not stressed. That relationship might change sooner than external evidence of plant growth change if environmental stresses occur. For this reason, key nutrients in pine needles are studied in the fall of each year.

Since it is necessary to relate plant nutrients to environmental factors that existed as long as two years previous to collecting samples, data are not available for 1984 (when the seedlings were planted) or for 1985. Data analysis has been completed for 1986 through 1990.

Nutrient concentrations have been in the ranges considered normal for red pine and existing site conditions. Some statistically significant differences have been observed among the sites, however. Concentrations of two nutrients in samples from the antenna and ground terminal sites were lower than the concentrations in samples from the distant site in 1990. The reasons for the differences remain unexplained. Soil nutrient analyses must be completed for 1991, and 1992 plant nutrient data are needed to interpret the observations.

4.1.5.7 Root-Fungi Associations. The fungi/red pine relationship known as mycorrhizae has been used by scientists to determine whether tree growth might be affected by stresses such as acid rain, ozone, and air pollution. The fungi are useful as indications of stress because they are nourished by the photosynthetic process that occurs in trees, and in return they help the trees obtain water and minerals from the soil.

Three types of mycorrhizae are found on the fine roots of pine seedlings taken from the three study sites. They are known to scientists as Type 3 (the most dominant at the study sites), Type 5, and Type 6 (the least common). They are distinguishable by color and look like fungal growths on the roots.

The total numbers of mycorrhizae have been quite similar at the three study sites each year. As is evident in Figure 30, the total numbers vary from one year to the next, but no site has consistently produced many more nor many less root fungi than the others. Nearly 30 environmental factors are included in the analysis of data. To date, no evidence has been found to suggest that ELF EM fields should be expected to disrupt the symbiotic relationship that exists between trees and mycorrhizal fungi.

4.1.5.8 Herb Studies. The herb starflower, *Trientalis borealis* Raf, shown in Figure 31, is an important plant in northern hardwood forests. The species has been studied extensively, so there is abundant literature to use as references for understanding results obtained in this project.

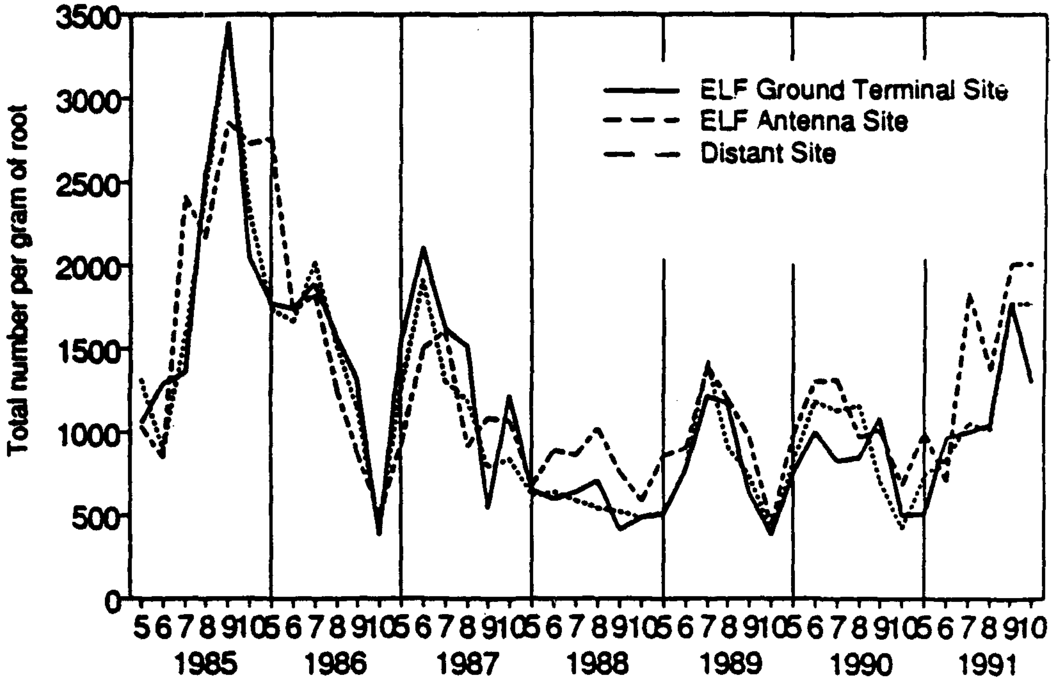


FIGURE 30. DESIRABLE ROOT FUNGI ON RED PINE SEEDLINGS ARE NEARLY THE SAME AT THE THREE STUDY SITES.

Two characteristics of starflower are being examined at the antenna site and at the distant site. One characteristic relates to the timing of processes called phenological events, which include the following:

- timing of stem growth
- bud opening
- leaf expansion
- flowering and fruiting
- the natural yellowing and browning of leaves

The other characteristic being followed relates to what are called morphological processes, which include the following:

- leaf area
- stem length
- number of buds and leaves
- number of flowers and fruit

Starflower specimens are examined periodically between April and August of each year at each site. The observations, counts, and measurements are transformed into plots like those shown in Figure 32. Some plots can be interpreted visually quite easily, but others cannot. In either case, the data

FIGURE 31. THE HERB STARFLOWER WAS SELECTED FOR STUDYING PLANT RESPONSES TO ELF EM FIELDS.

are analyzed and tested statistically to determine whether variations observed between the two sites and from year to year are significant.

Many of the observed variations in data accumulated since 1985 have turned out to be insignificant. Others have been statistically significant, and therefore require explanation. Soil temperature, solar radiation, and the density of trees on each site help explain most of the significant variations found in the data. Exposure to ELF EM fields, which has occurred full-time for only two years thus far, does not appear to influence plant phenological processes or morphological events. This conclusion will be tested more rigorously as ELF transmitter operations continue and additional herbaceous plant data are obtained.

4.1.6 Native Bees Project Results

Bees are relatively rare in forests, but are nevertheless important because they pollinate flowers. Two native species called *Megachilidae*, one somewhat smaller than the other, are found in forest openings near the NRTF-Republic in Michigan, and are being studied in this project.

There is a relatively extensive body of literature about the relationship of bees and the earth's magnetic field, as there is about EM field effects on bees.[25, 29-36] The species examined in this project have

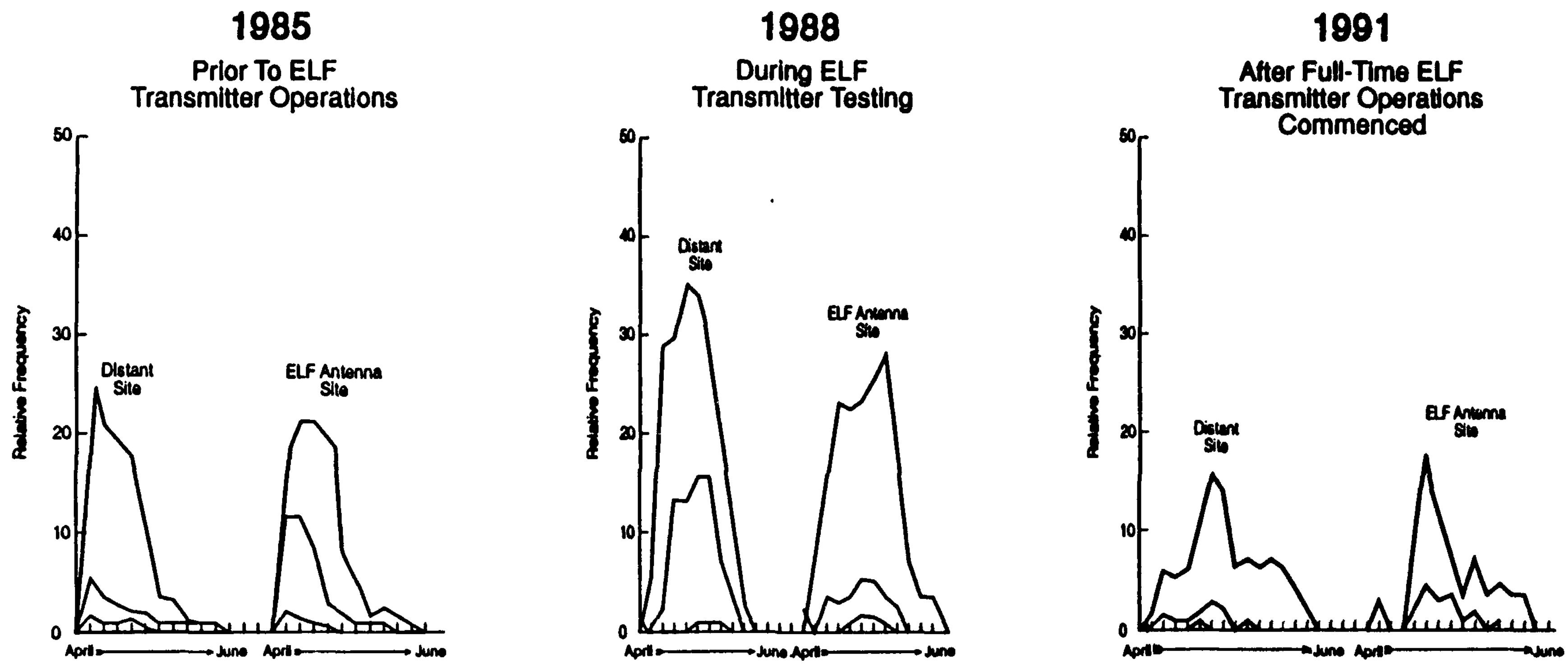


FIGURE 32. VARIATIONS IN STARFLOWER GROWTH BETWEEN SITES ARE DUE TO VARIATIONS IN NATURAL ENVIRONMENTAL FACTORS (THE VISIBLE PRESENCE OF BUDS AS THE GROWING SEASON PROGRESSES IS SHOWN).

been used by others for pollinating crops and fruit trees,[40] and that literature is helpful in understanding the observations made in this project.

Megachilid bees, unlike honey bees, are solitary creatures. Each female constructs and provisions her own nest. Nests are built in holes made in dead logs by boring insects, but the bees readily accept artificial trap nests, a distinct advantage in this project. Artificial nests for this project (blocks of wood with drilled holes) are placed in hutches like that shown in Figure 33 and dispersed in two places near the ELF transmitting antenna and at two distant sites.

The female constructs her nest according to a unique architecture illustrated in Figure 34. The female creates a cell with leaf pieces and fills it with pollen and nectar, then lays an egg. The size of the cell is determined by whether the female will produce a female offspring (a fertilized egg) or a male offspring (an unfertilized egg). Cells and provisions for female offspring are larger than for male offspring, and are built deepest in the nest.

The female caps the first (deepest) cell with leaf pieces, dirt, and bits of wood. Then she proceeds to build and provision the next cell for the next egg. The process continues until the nest is almost filled with cells. The nest is completed by plugging it with chewed leaves, dirt, chewed wood, and other available material. Empty spaces are sometimes left within the plug by the species *Megachile relativa*, but the species *Megachile inermis* produces plugs without empty spaces. An indentation often is left at the open end of the nest by both strains.

Females may build one or more nests before dying at the end of the season (adults live only one season). Assuming that parasites do not invade the cells, the eggs hatch, the larvae feed on the provisions over winter, pupate in the spring, and emerge as adults in June and July.

4.1.6.1 Nest Observations. Five distinct observations are being made to study nest building by the two strains of native megachilid bees. The observations are:

- the number of completed cells in each nest
- the ratio of male to female cells
- the sizes of male and female cells
- the preferences (if any) for cells opening to the east or west versus cells opening to the north or south
- the sizes of bees emerging from the nests

Variations in these data have been observed between study sites and from year to year. Few of the variations have been consistent, however. For example, no one site has consistently yielded more or fewer nests than the other study sites, except that the *M. inermis* bees have produced more nests at the antenna sites than at the distant sites every year. However, the individual cells have been larger at

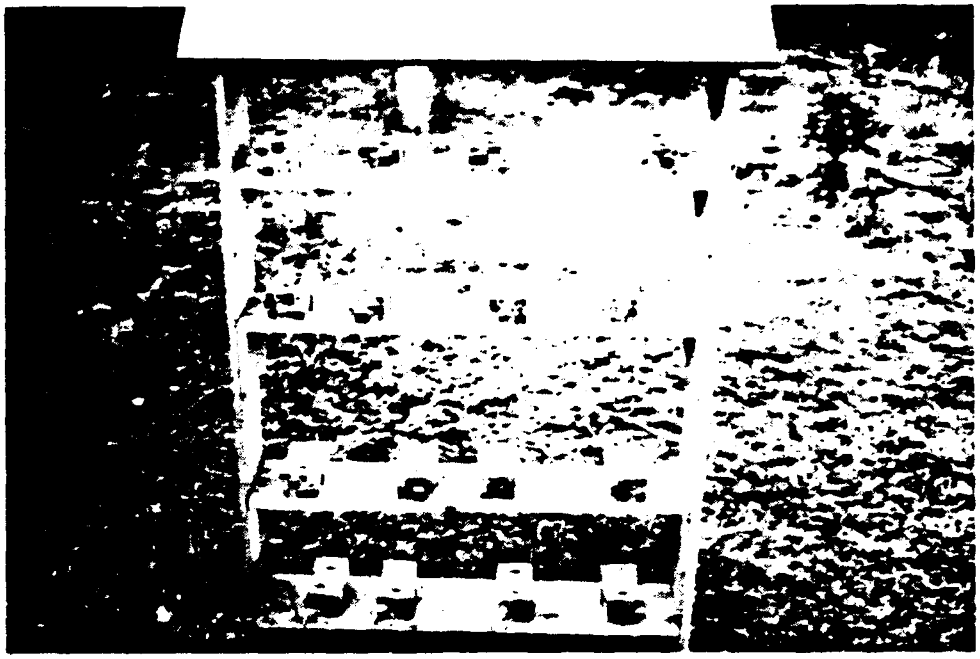


FIGURE 33. ARTIFICIAL NESTS PLACED IN HUTCHES ARE USED TO STUDY NATIVE BEES.

the distant sites. No other consistent trends in cell size have been apparent except that female cells are larger than male cells (an expected outcome).

The male-to-female ratios at the sites have been lower than 2:1 and as high as 10:1 in some years. One distant site has always produced smaller bees than the other sites, but otherwise there have been no apparent trends in sex or size data. Likewise, the numbers of cells per nest have varied considerably. To date, no systematic preference for north-south or east-west nests has been seen.

Completed analyses have largely explained variations in observations. Weather and the availability of flowers are two key factors, especially for the smaller bees—the *M. relativa*. *M. relativa* build fewer cells in dry years, when flowers are less abundant. After two years of full-time ELF transmitter operations, no connection between observations and ELF EM field exposures has been found.

4.1.6.2 Mortality Observations. Mortality may occur at any time after the adult female lays her eggs, up to the time that the next generation emerges from the nest nearly a year later. Weather throughout the nesting period can have a large impact on mortality, and makes year-to-year comparisons somewhat uncertain. Another difficulty is that cuckoo bees invade nests, consume the provisions (causing death in the *Megachile* larva), then go through the same reproductive process as the *Megachile*. In fact, it is virtually impossible to distinguish the cuckoo bee prepupa from a megachilid prepupa, and dead prepupae are counted when nests are opened to determine mortality. Despite the difficulties, mortality

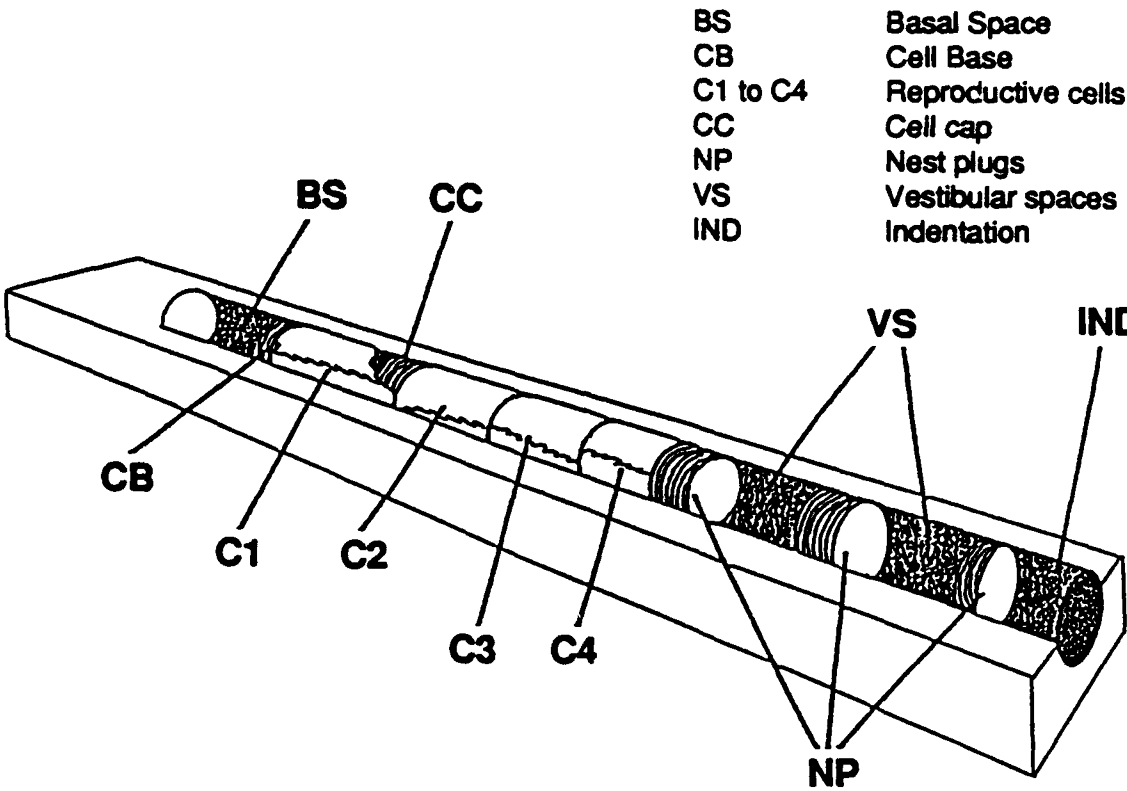


FIGURE 34. CUTAWAY VIEW OF THE ARCHITECTURE OF A MEGACHILE NEST.

has been examined and analyzed to ascertain whether survival in the nest and EM field exposure might be associated.

Mortality, regardless of cause or the time at which it occurs, typically has claimed the insects (the Megachilid and cuckoo bees) in fewer than about 40% of the *M. relativa* cells in years when mortality was low (all years except 1987 and 1988). Mortality was in the range of about 60% in the two high- mortality years (1991 data analysis is not yet complete). Only 1986 seemed to be somewhat remarkable for the *M. inermis* nests: mortality was seldom more than 20% that year, compared to about 40% in all other years.

Based on the sampling and analytical methods used to interpret data, one should expect that one of every 20 tests for associating mortality with EM field exposure will erroneously indicate that a relationship exists. To date, 10 tests for association have been completed, and three have indicated a very weak association. They are:

- EM field exposure near the transmitter may increase mortality slightly (unfavorable weather has a greater impact)
- mortality due to EM field exposure, if it occurs, occurs over the winter (the cocoon stage of development)
- nest orientation may be a factor if EM field exposure causes increased mortality

Although the associations are barely significant statistically, they cannot be dismissed as "false positives." At least one more full year of 76 Hz field exposure is necessary to either support or refute the associations identified so far.

4.1.6.3 Foraging Activity. After laying an egg, the female megachilid makes several very rapid flights in and out of the nest before finally leaving to collect the first leaf to cap the occupied cell. Trips to and from the nest after the first cap leaf is put into place are less frantic.

The first three trips out of the nest have been timed to study foraging. There is considerable variability in the data for all study sites from year to year, and few consistent trends. Data analysis has not been completed, and at this time foraging behavior remains largely a mystery.

Observations of foraging are difficult to make because one must somehow be at the right place at the right time. Trips that last only seconds must be timed accurately to avoid observer bias. The work is labor-intensive, and productivity can be low. For these reasons, foraging activity has been discontinued as a study. Data analysis will continue, however, in an attempt to learn more about foraging behavior.

4.1.7 Small Mammals and Nesting Birds Project Results

Deermice and chipmunks are being studied as representatives of forest mammals that conceivably could be affected by exposure to ELF EM fields. Tree swallows and chickadees were selected to represent birds. The movements of deermice can be limited to relatively small areas in forests without apparent physiological or behavioral effects, and tree swallows readily accept man-made boxes for nesting. Both species accommodate occasional human intrusion fairly well, so they are used most extensively as subjects in this project. Chipmunks and chickadees are useful subjects for several specialized studies.

4.1.7.1 Deermouse Parental Care and Growth. Eighteen pairs of deermice are housed in large, escape-resistant enclosures like that shown in Figure 35 at each study site each year. Four litters of newborns are observed periodically. Parental care has been found to be a significant contributing factor in the growth of the offspring—some females produce larger offspring than others. Litters also differ in growth rates. No consistent trends with regard to study sites have been found; that is, deermouse growth appears to be largely independent of study site location.

FIGURE 35. LARGE ESCAPE-PROOF ENCLOSURES ARE USED TO STUDY DEERMOUSE PARENTAL CARE AND GROWTH.

Typically, teeth appear in young deermice in about six days, and their eyes open after about two weeks. These events, like growth, have not varied consistently among sites, suggesting that there is no apparent association between deermouse growth and ELF EM field exposure.

4.1.7.2 Tree Swallow Parental Care and Growth. Nest boxes like those shown in Figure 36 have been placed at the study sites to monitor tree swallow parental care and growth. The birds have built nests in most boxes at each site every year. Nesting appears to depend on the number of birds in each area, which varies according to weather.

Observations from year to year have not shown much variation, and there have been no consistent trends relative to study site preferences. The principal observations are listed in Table 6. Variations that have been observed have been related through statistical analysis to weather and distinct study site characteristics. Parental care seems to be critical in nesting success.

TABLE 6. SOME OBSERVATIONS MADE IN TREE SWALLOW NESTING AND GROWTH

Number of nest boxes with 2 or more eggs	43% to 90%, depending on site and year
Number of eggs in each next box	4 to 5
Eggs that successfully hatch in each nest	83% to 95%, depending on site and year
Mortality rate	2% per year
Date of eye opening	5 to 8 days
Date of first feathering	7 to 10 days
Reasons for variability in observed data: Differences in parental care; predation of nests; weather	

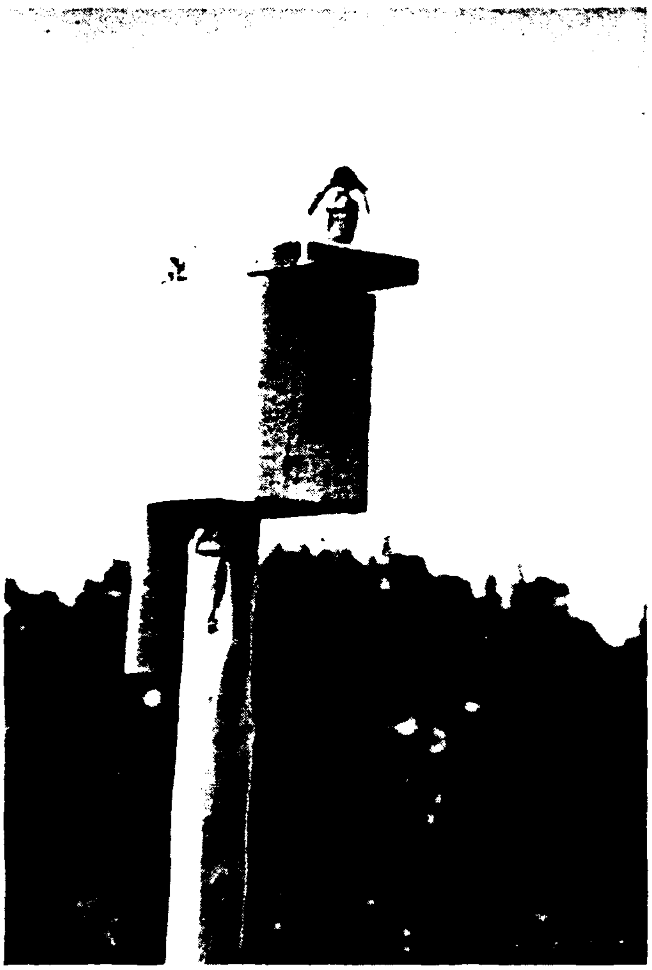


FIGURE 36. NEST BOXES ARE DISTRIBUTED AT STUDY SITES TO STUDY TREE SWALLOW NESTING AND GROWTH.

4.1.7.3 Small Mammal Homing. Individual, unrestrained chipmunks and deermice are being observed at one study site near the antenna and at a distant study site to examine homing behavior. Trapping stations have been set out at each study site. An individual is selected for observation if it is captured three consecutive times—an indication that the individual is indeed in its home range. The selected animals are then displaced 450 m (1350 ft) from where they are trapped, and their return is timed.

The percentage of animals that return to the point where they were trapped has varied widely from year to year since 1986. For example, the rate of return at the distant site in 1986 was only 23% for deermice, but the rate of return in 1990 was 83%. Data for chipmunks show a similar high variability from year to year. Data analysis has not yet identified the factors that may be most important in small mammal homing ability.

4.1.7.4 Tree Swallow Homing. The homing ability of tree swallows in the presence or absence of ELF EM field exposure is being examined much like the homing ability of deermice and chipmunks. Selected tree swallows are taken from nest boxes at the antenna site and at the distant site. The birds are then released 30 km (about 18 mi) from the sites. The numbers returning to their home nests within five hours of release are counted.

This series of observations has produced consistent results. At least 90% of the birds taken from nest boxes at the antenna site have returned to their home nest every year since 1986. The return rate at the distant site has been lower, as shown in Table 7. Furthermore, birds have returned to nests near the antenna sooner than birds have returned to distant sites. These data also are listed in Table 7.

TABLE 7. OBSERVED HOMING SUCCESS FOR TREE SWALLOWS

	Return Rate, %		Return Speed, mph	
Year	Antenna Site	Distant Site	Antenna Site	Distant Site
1991	97	62	8.8	6.6
1990	98	77	8.3	6.8
1989	100	94	10.3	7.1
1988	90	87	8.8	6.2
1987	97	66	7.6	5.8
1986	90	77	8.2	7.4

Observations thus far do not indicate that ELF EM exposure is involved in the higher homing success at the antenna study site. Birds at that site demonstrated better homing even before the ELF

transmitting antenna was operated. Despite a variety of sophisticated statistical analyses, the reason (or reasons) for the observed variations in data has not been identified, and numerous possibilities have been dismissed.

4.1.7.5 Metabolism Studies. Studies of parental care and growth and studies of homing are made between late spring and early fall, when weather conditions are most favorable to wildlife. It is conceivable that EM field exposure effects might be more likely to occur during winter, when cold weather represents a natural stress on animals.

Animals take in more oxygen to maintain their body temperatures as weather becomes more severe. At some point, temperature may become too cold for survival. Oxygen consumption before that point is encountered is a measure of the peak metabolism of the individual. Peak metabolism has been determined for deermice and for chickadees taken from an antenna study site and from a distant study site.

Peak metabolism data have been analyzed for two years prior to ELF antenna operations and for two years since full-time operations commenced. Measured data do not indicate that metabolism has been influenced by 76 Hz EM fields produced by the Navy's communications system.

4.1.8 Results of the Bird Species and Communities Projects

4.1.8.1 Results of Wisconsin Studies. A study to examine whether birds in the Chequamegon National Forest in Wisconsin might be affected by ELF EM fields from the NRTF-Clam Lake was initiated in 1984 and was completed in 1989.[42]

Birds at five sites near the NRTF-Clam Lake and birds at five distant sites were identified by species and by guilds. (Certain species are classified as a guild by similarities in habitat preferences and other characteristics.) The places where censuses were made are identified in Figure 12. Censuses were made between May and September in each year, always in the early morning hours. Vegetation characteristics were examined and recorded for each study area. All data were analyzed statistically to identify factors that varied and relationships between variables (i.e., whether the variation in factor x was caused by a change in factor y).

Typically, about a dozen species could be identified at each location in May and June, and by August fewer than one-half dozen remained at the sites. As Figure 37 shows, these trends were found at distant sites as well as at sites close to the ELF transmitting antenna. Numbers of birds also were similar at all locations. These observations suggested that a large influence on bird populations from ELF transmitter operations was not likely.

Of the 125 species of birds identified during this study, 38 were found to differ statistically when the numbers found on sites near the antenna were compared to the numbers found on distant sites.

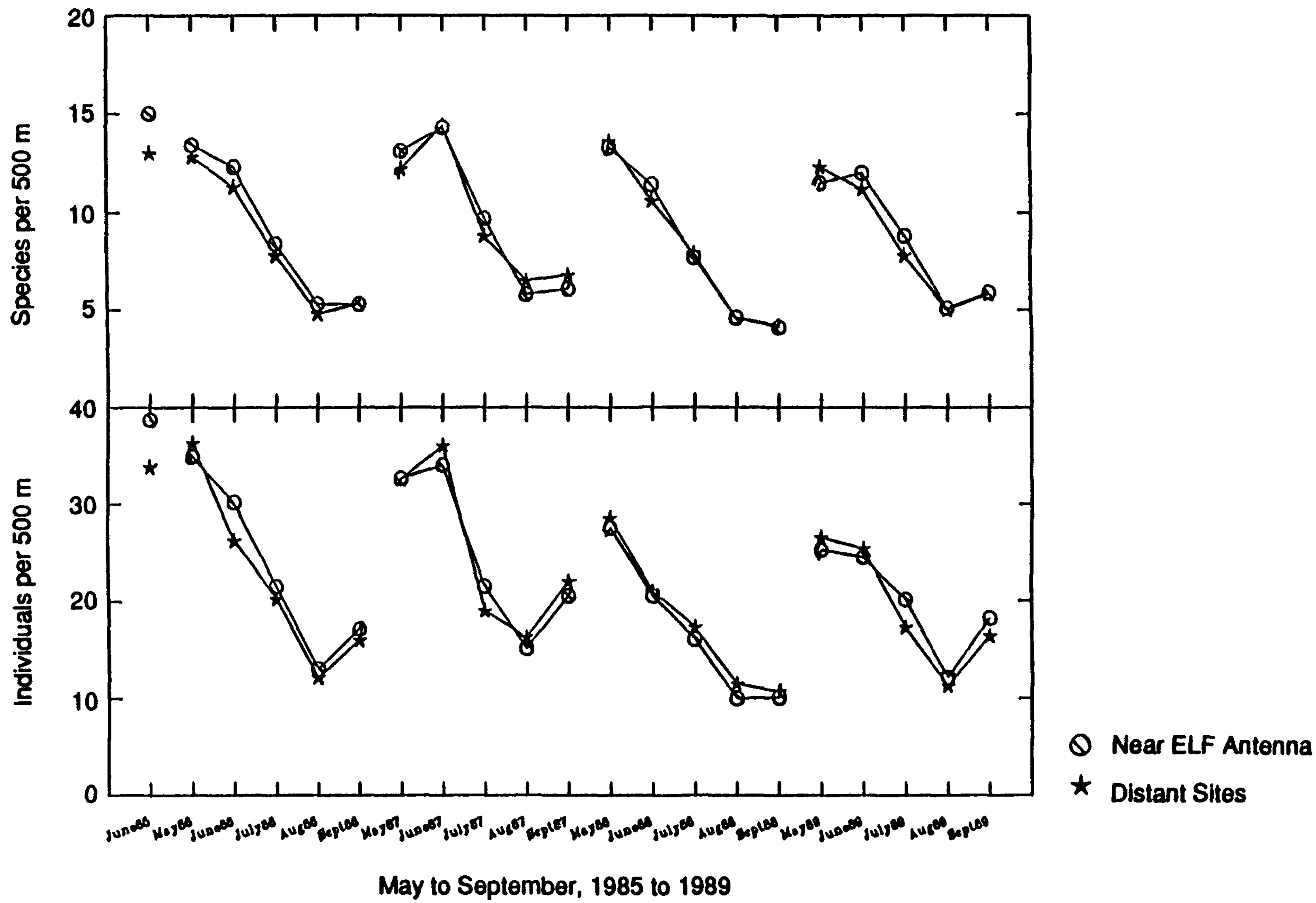


FIGURE 37. THE NUMBER OF SPECIES AND THE NUMBER OF BIRDS WERE NEARLY THE SAME NEAR THE CLAM LAKE TRANSMITTING ANTENNA AS AT THE DISTANT SITES.

Nineteen species were more abundant in distant areas, 16 more abundant in treatment areas, and three not consistently abundant in either area. Only a few species were consistently and significantly more abundant on either near or distant sites among seasons within a year, or within seasons between years.

Birds common to northwestern Wisconsin belong to any of five habitat guilds. One would expect that birds belonging to the coniferous (evergreen) habitat would be more abundant near the ELF antenna, and that birds belonging to the deciduous habitat would more likely be seen at distant sites. Observations confirmed expectations for all five habitat guilds populating the region. Likewise, no unexpected results were found for five foraging guilds. In other words, birds that prefer ground insects and fruit were found where they were most expected to be, flycatchers were where they were most expected to be, and so on.

Variations in bird species and numbers of birds could be related to weather conditions and time of year as well as to habitat and feeding preferences. No firm associations could be identified with exposure to EM field intensities produced by the ELF antenna. Birds closest to the antenna were found where 76 Hz electric fields in air were as low as 6 V/m and as high as 470 V/m, a range of nearly 100:1 in intensity. The magnetic flux densities were in the range from 0.04 to 10 milligauss (mG), also a range of about 100:1. The conclusion that EM fields of these intensities have no evident influence on bird populations is based on more than 40,000 observations.

4.1.8.2 Results of Michigan Studies. Studies of bird populations and communities in Michigan are designed much like those conducted and completed in Wisconsin, with one important exception. There was no data base in Wisconsin for characterizing birds prior to initiating ELF transmitter operations. Data analysis was therefore limited to comparing observations of birds exposed to several levels of EM field intensity.

Observations of birds in Michigan commenced before ELF transmitter operations were initiated at Republic. As a result, comparisons can be made not only of observations made at places with different levels of 76 Hz field intensities, but also of observations made at each study site before ELF transmitter operations began, and after full-time operations were initiated.

Typically, about 600 to 1200 birds have been identified at the 10 study areas in May of each year in Michigan. The population increases somewhat during June, but by August the population drops to about 400 to 800 individuals. Yearly variations can be related to weather conditions. Site-to-site variations can be related primarily to differences in habitat and food supplies.

The number of observed species has almost always been somewhat higher at distant sites than at sites close to the ELF antenna from May until August of each year. There is a correlation between the number of species and the availability of preferred habitats. As was found in Wisconsin, the species are distributed as would be expected from knowledge of bird guilds. About 45 to 60 species have been

identified near the ELF transmitting antenna each year, and the number of species at distant sites has varied between 45 and 70.

Many ornithologists believe that bird populations have dropped in the last several years. The results of this project tend to support that belief. Numbers of birds identified in June have been dropping at all study locations since 1985. Examples of the yearly reductions for four migrant species are illustrated in Figure 38.

Two years of full-time ELF transmitter operations is too short a time to support an unqualified conclusion that exposure to 76 Hz EM fields has not influenced bird populations in the region. Observed variations from year to year and from study site to study site have been quite large. Statistical analyses have been successful in identifying that much of the variation is most likely due to changes in weather conditions from year to year and different preferences for habitat and food from site to site. At this time, statistical analyses have not indicated that ELF EM field exposure can be related to observed variations.

4.2 Results of the Wetlands Ecosystem Project

The wetlands ecological study was conducted from 1983 to 1987 at 11 bogs at various distances from the NRTF-Clam Lake in Wisconsin (see Figure 12).[43] Several species of bog plants, trees, and prepared samples of cellulose (wood pulp) were studied. Six study sites were used in each bog, so in reality a total of 66 plots were examined.

A number of different plant species were studied during the project, but most studies concentrated on the black spruce as a representative tree, labrador tea and leatherleaf as examples of shrubs, the herb known as *Smilacina*, and mosses.

Characteristics of water were identified to ensure that the bogs were reasonably similar with regard to water chemistry. The vegetation at each site was characterized for the same reason. Three distinct factors were then monitored:

- decomposition of cellulose and labrador tea leaves
- nutrients in the leaves of four species of plants
- the stomatal resistance of labrador tea leaves

Stomatal resistance is a measure of the opening and closing of stomata, by which plants respond to carbon dioxide, sunlight, and other environmental influences.

4.2.1 Decomposition

Decomposition of labrador tea leaves could not be related to 76 Hz EM field exposure (the same conclusion applies to cellulose samples). An example of decomposition over a period of one year is shown in Figure 39. An illustration of the lack of an EM field effect is evident in Figure 40—the data are

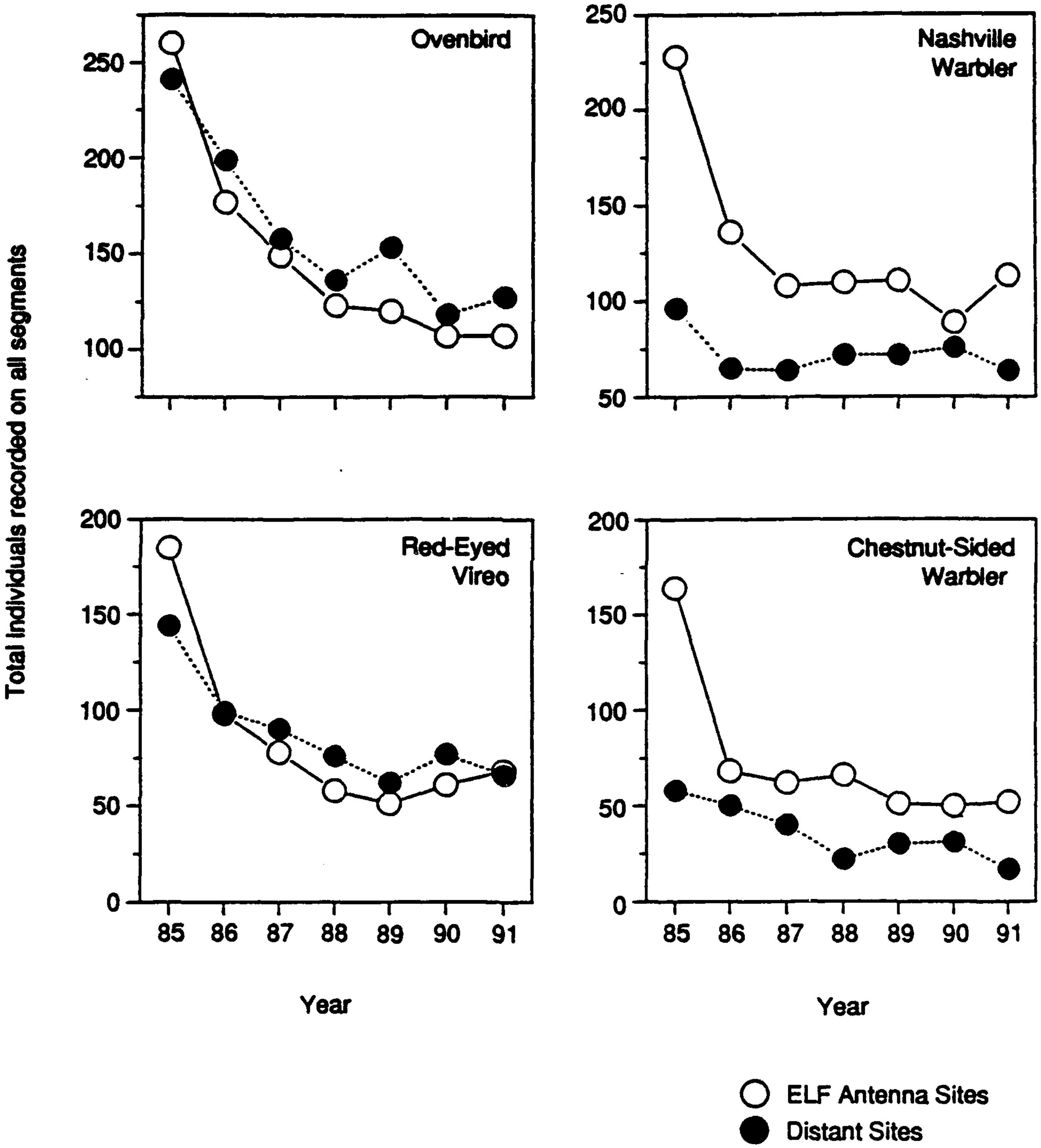


FIGURE 38. NUMBERS OF MIGRANT BIRDS OBSERVED EACH JUNE FROM 1985 THROUGH 1991 HAVE BEEN DROPPING AT ALL STUDY SITES (TREND IS CONSISTENT WITH NATIONAL OBSERVATIONS).

scattered on the diagram. An effect would be demonstrated if any set of similarly shaped points could be connected by a straight or smooth line.

4.2.2 Nutrients in Plant Leaves

Wetlands in the upper Great Lakes region are nutrient-poor. As a result, plants in bogs have evolved differently than woodland plants. For example, the evergreen labrador tea and leatherleaf lose their leaves about every two years. Black spruce needles only fall every several years, and *Smilacina* takes nutrients from its old leaves before new ones form. If ELF EM fields were to affect nutrients stored in leaves, not only plants might suffer, but biological cycling within wetlands could be damaged as well. A leaf nutrient study was especially important for this reason.

It was found that concentrations of leaf nutrients changed from month to month, from year to year, and among bogs. Examples of the findings are illustrated in Figure 41. A total of 79 statistical tests were conducted to interpret the observations. A relationship between 76 Hz EM field exposure and data variability was found in only five of the tests. That number of positive results is the same as would be expected from chance alone, and the investigators concluded that EM field exposure was not influencing nutrients in bog plant leaves.

4.2.3 Leaf Stomatal Resistance

Stomatal resistance is difficult to measure, and results are difficult to interpret. The stomata of leaves open and close in response to many variables. Several different methods were used in attempts to measure stomatal resistance on intact plants in the study bogs. Despite numerous precautions to ensure that the process of measuring and the handling of leaf samples would not bias data and analysis, no consistent results could be obtained. Some of the environmental variables known to affect stomatal opening and closing could be identified in studies conducted in the bogs, but no confident evaluation of the data could be made. It is unlikely that exposure to ELF EM fields affects stomatal resistance, since no relationship was found between exposure and leaf nutrients; however, this study did not produce corroborating evidence.

4.2.4 Electromagnetic Field Intensities

Because each bog studied in this project was a different distance from the Navy's ELF transmitting antenna at Clam Lake, each represented a different exposure of bog plants to 76 Hz EM fields. Table 8 shows the ranges of measured field intensities for the four bog categories. Electric field intensities varied by a factor of 600 between the bogs closest to the ELF transmitting antenna and those farthest from the antenna. The magnetic field range was about 100:1 between the closest and farthest bogs.

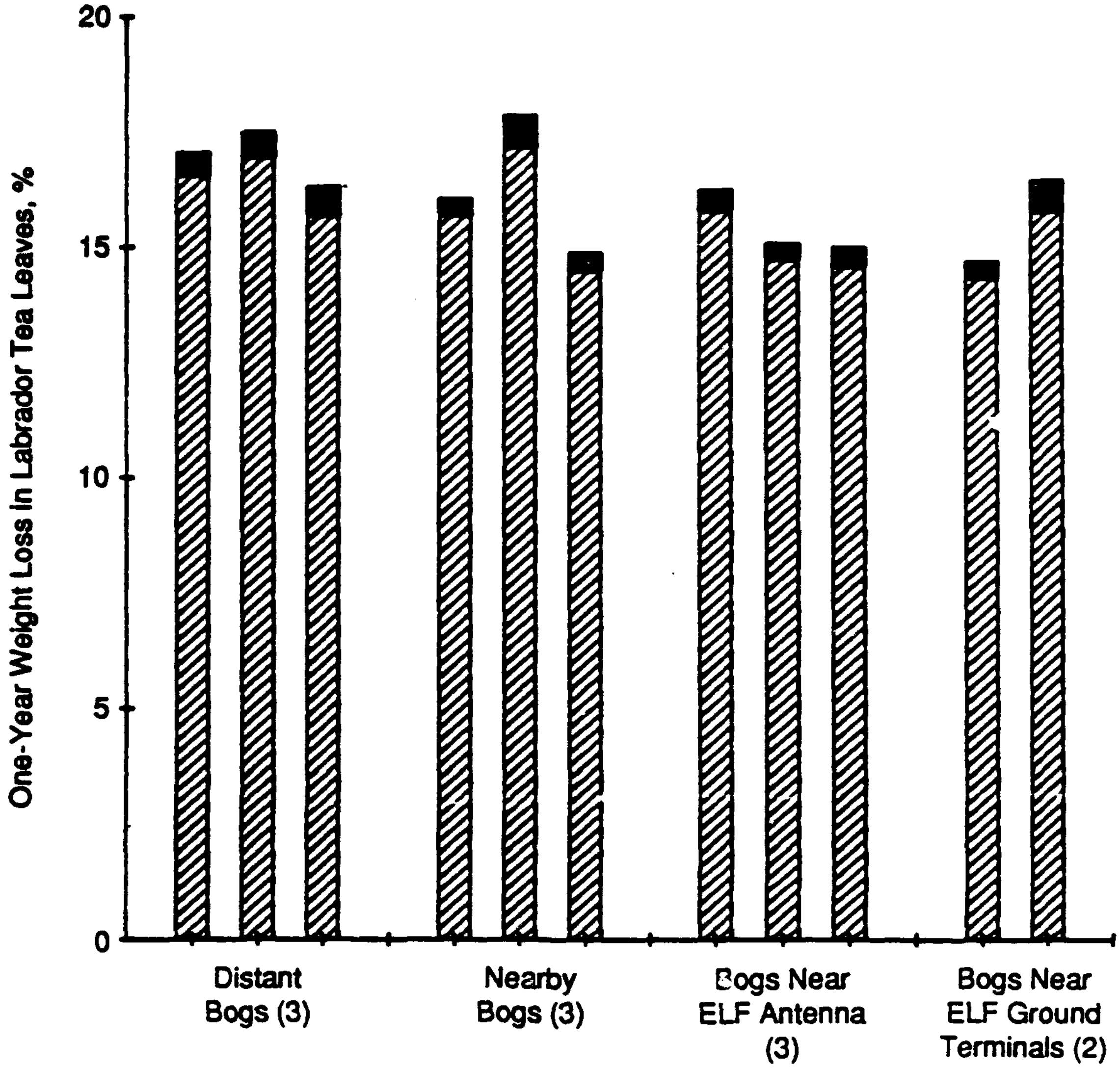


FIGURE 39. DECOMPOSITION OF LABRADOR TEA LEAVES WAS NEARLY THE SAME AT ALL PEAT BOGS.

TABLE 8. RANGES OF 76 Hz ELECTROMAGNETIC FIELD INTENSITIES AT BOGS USED FOR WETLANDS ECOLOGY STUDIES

Bog Location	Electric Fields in Air, V/m	Electric Fields in Soil, V/m	Magnetic Flux Densities, mG
Near ELF ground terminals	0.1 to 0.6	0.1 to 0.45	0.2 to 2
Near ELF transmitting antenna	0.09 to 0.25	0.1 to 0.16	6 to 20
Nearby bogs	0.008 to 0.06	0.004 to 0.06	0.08 to 0.50
Distant bogs	0.001 or less	0.0007 to 0.0014	0.012 to 0.017

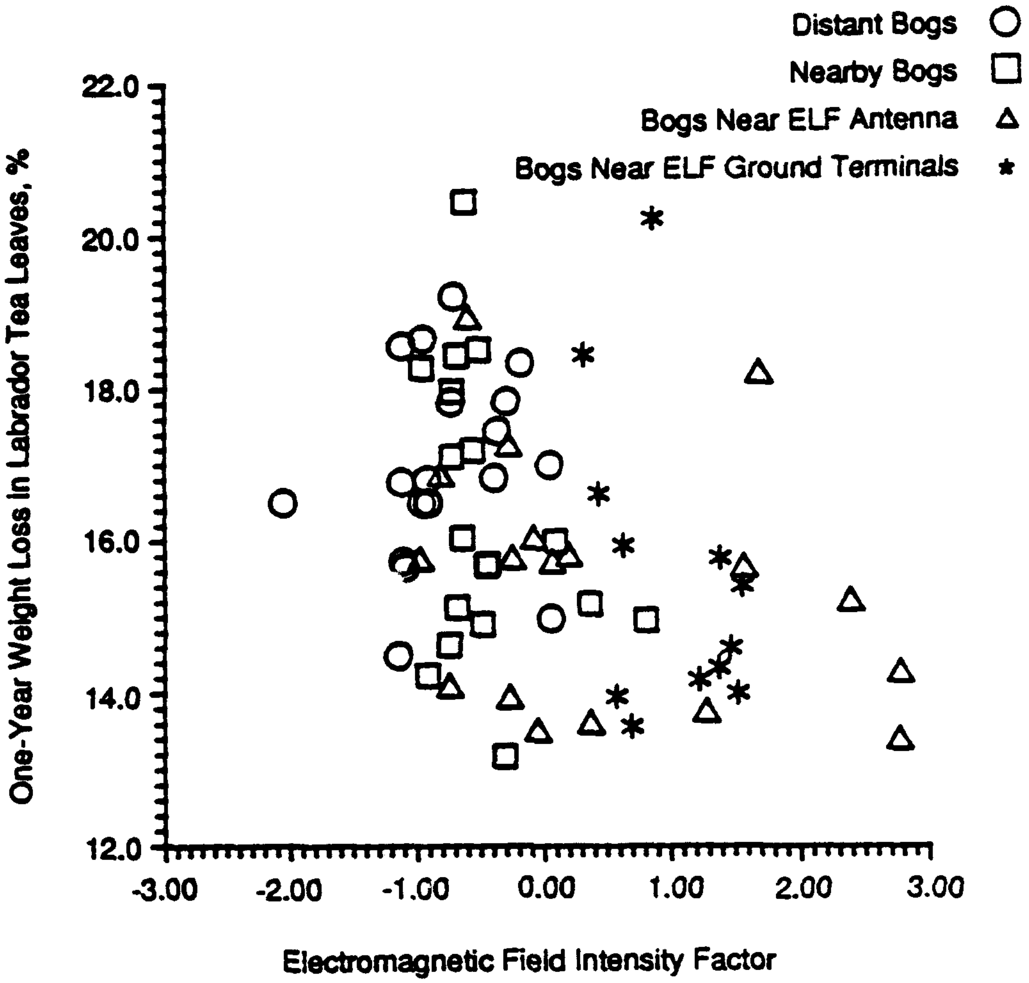


FIGURE 40. SIMILARLY SHAPED POINTS CANNOT BE CONNECTED BY STRAIGHT LINES, INDICATING THAT DECOMPOSITION IS NOT AFFECTED BY EM FIELD EXPOSURE.

4.3 Aquatic Ecosystem Projects

The aquatic ecosystem projects are all conducted on the Ford River, the source of which is in northern Dickinson County and southern Marquette County. The river eventually enters Green Bay south of Escanaba. Its course crosses the ELF antenna.

One study site is located where the north-south leg of the antenna crosses the Ford River. One distant site is located about five miles downstream. Three other sites near the antenna and a distant site upstream of the antenna also are being studied. All study sites are identified in Figure 11. The sites selected for the studies are as well matched physically and chemically as possible among those sites that also satisfy other important research requirements.

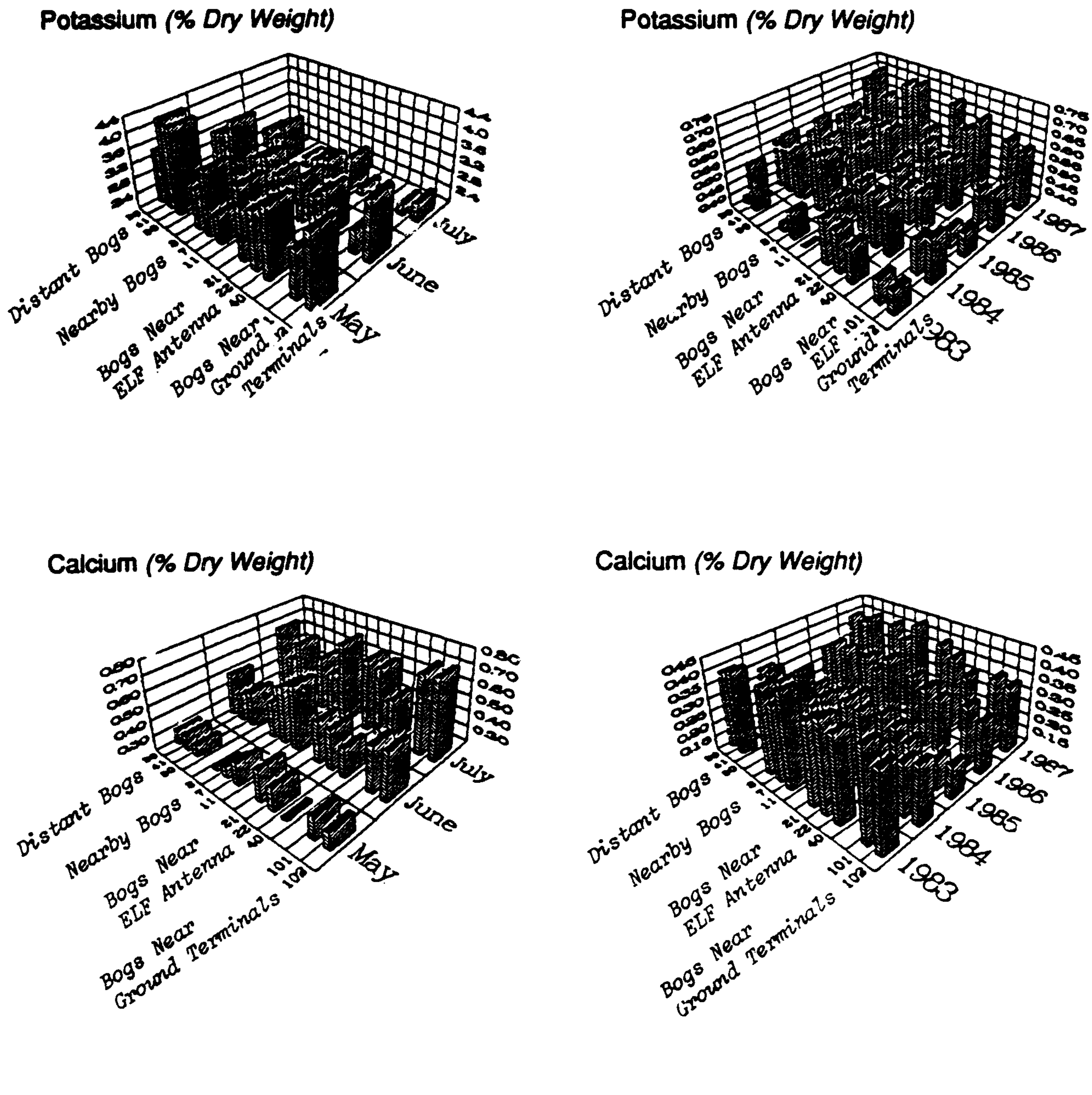


FIGURE 41. NUTRIENTS IN BOG PLANT LEAVES VARIED SEASONALLY, YEARLY, AND AMONG BOGS, BUT VARIATIONS WERE NOT RELATED TO ELF EM FIELD EXPOSURES.

One of the three aquatic projects studies algae that attach to rocks on the river bottom; another is concentrated on river insects; and the third is a study of fishes that inhabit the river. The first is principally an examination of the river's primary productivity; the second and third monitor the consumer communities.

4.3.1 Natural Environmental Factors

Physical and chemical characteristics of the Ford River at the study sites differ only slightly and do not represent impediments to analyzing observed ecological factors. Many of the differences could be related to land use along the river, and generally were evident in the larger values recorded downstream. For example, downstream water was somewhat harder, was more alkaline, and had higher concentrations of chemicals than water closer to the river's source. Some differences tended to favor upstream water, however. There was slightly more dissolved oxygen upstream, and there was more chloride in the river near the highway M-95 crossing than at the ELF antenna crossing.

4.3.2 Periphyton Project Results

Organisms called diatoms account for 90% of the algae that live on rocks in the Ford River. In order to increase the efficiency of this project, glass slides are placed in the river and then removed periodically after diatoms collect on the plates. It would be much more difficult and imprecise to examine diatoms on rocks.

Seven characteristics of the diatom community are monitored:

- species diversity and evenness
- colonization patterns
- accumulation patterns
- chlorophyll levels
- photosynthesis and respiration
- cell density
- cell volume

4.3.2.1 Species Diversity and Evenness. More than 50 species of diatoms have been identified at the study sites. Nine of the dominant species are being studied. Two are usually present in the greatest numbers, but month-to-month changes in dominance occur naturally every year. For example, one species may be dominant in early sp:ing and another may be dominant in late summer. A species may account for 80% of all diatoms in June, but less than 10% of the population in December. Some species never account for more than 10% of all diatoms.

A statistical analysis of the data revealed that species diversity and evenness changed seasonally in the same ways at all study sites both before the ELF antenna was installed and after the antenna

became fully operational. Data trends after two fully operational years suggest that no ELF EM field exposure effects are taking place.

4.3.2.2 Colonization Patterns. Colonization is a study of the rate at which organisms appear on rocks, or, as is the case here, on glass slides. Colonization over 14-day periods is determined during the summer months. Colonization is slower in cold months, so sampling periods range from 28 to 56 days. No changes have been observed in colonization among the study sites.

4.3.2.3 Accumulation Patterns. Organic accumulation on rocks and glass slides, like colonization patterns, is a measure of river productivity. As noted above, no significant differences in colonization have been observed among study sites. Consistent patterns also have been absent in the accumulation of organic mass on glass slides, except for a seasonal effect. Organic mass tends to peak each year in July and August. Accumulation is much lower during winter months, especially if ice covers the river.

Only quite large differences in organic accumulation can be detected by the methods used in this study. For this reason, no conclusion about ELF EM field influences on accumulation is warranted after only two years of full-time ELF antenna operation.

4.3.2.4 Chlorophyll Levels. Chlorophyll is the substance that gives plants their pigmentation. A measure of chlorophyll is a good indication of a plant's productivity. As might be expected, chlorophyll is highest when river water is warm and drops to much lower levels during winter.

Chlorophyll levels have varied over wide ranges every year. Additionally, there seems to be a trend of decreasing chlorophyll since about 1987, and especially since 1989. Chlorophyll has peaked as early as March in some years, but in most years maximum chlorophyll has been detected in July and August.

Variations in chlorophyll data appear to be related mainly to weather and river conditions. Summers in the last several years have been hot and dry, and, as a consequence, water levels in the Ford River have been low. The significant drop in chlorophyll observed at some study sites in 1989 corresponds roughly to the initiation of full-time ELF antenna operations. However, statistical tests of yearly data do not indicate that chlorophyll and exposure to ELF EM fields are likely to be related.

4.3.2.5 Photosynthesis and Respiration. Photosynthesis is monitored from rock samples covered with periphyton to evaluate gross primary production. Changes in dissolved oxygen are measured during the summer months, when growth is intense and indicates community photosynthesis. None of the data collected since 1984 indicate that photosynthesis or respiration have been affected by EM field intensities produced by the ELF antenna.

4.3.2.6 Cell Density. The density of cells has varied in much the same way as colonization, accumulation, and chlorophyll. Cell density is low during winter months and peaks during warmer months. Peak cell density may occur early in spring or later in summer.

There has been a trend in the last several years for cell density to decrease at most study sites. This trend is much like that observed in chlorophyll data, and it has not been related to ELF antenna operations.

4.3.2.7 Cell Volume. As stated earlier, the colonization, accumulation, chlorophyll, and cell density of diatom algae on glass slides in the Ford River all peaked during warm weather and reached minimum levels during winter months. The data on the volume of individual algae cells and the total volume of cells on each glass slide are a mirror image of the data previously described. Cell volume is lowest during the summer, when the other characteristics are highest, and the highest cell volumes correspond to the lowest colonizations, accumulation, etc.

Statistical tests of the algal volume data indicated that monthly, yearly, and site-to-site variations were related to weather and river conditions. There were no indications that ELF EM field intensities were related to observed variations in the data.

4.3.3 Aquatic Insects Project Results

This project includes two distinct studies. One is focused on insects that live on the bed of the Ford River, and the second concentrates on the insect community involved in the breakdown of leaves that fall into the river. The study of leaf breakdown, or processing, includes monitoring colonization patterns, determining the total mass of insects, the weight of individuals, and the breakdown of summer leaves and autumn leaves.

4.3.3.1 Species of River Insects. As many as 3000 individual insects might be included in a scientific sampling of aquatic insects. Classifying each individual would be so time-consuming as to be impractical: insects common to the Ford River show as many as 184 distinctive characteristics. However, an alternative way of classifying insects is available and is being used in this project to detect whether ELF EM field exposure might influence the aquatic insect community. Insects are simply classified according to their feeding habits. Some insects are collectors and gatherers, some are filter-feeders, some are grazers or shredders, and others are predators. Each functional group is being monitored in this project.

Seven baskets of stream bed material are taken each month from May through September from each study site (see Figure 42). Insects found in the material are separated into their respective groups to determine the composition of the community. Communities change from spring to summer, and from summer to fall.

FIGURE 42. RIVER MATERIAL IS REMOVED FROM STUDY SITES PERIODICALLY TO STUDY AQUATIC INSECTS.

It has been observed that the insect communities among sites are least alike early in the spring and most alike in autumn. Large variations have occurred from year to year. Water temperature changes and changes in river flow have large influences on the aquatic insect community. No firm evidence has been found as yet that an ELF EM field exposure effect on aquatic insect species is taking place. An effect, if it were to occur, would have to be very large to be detected, because river flow has changed dramatically during the spring since 1987 and has impacted the insect community. Figure 43 shows how spring flow has been reduced because of relatively warm, dry winters.

4.3.3.2 Insect Mass. Figure 44 vividly illustrates how reduced spring flow in the Ford River since 1987 has affected the aquatic insect community. Insect mass reductions are not sustained beyond the spring, however. Summer and autumn insect masses have varied from year to year at all study sites, but no general reductions comparable to 1984-1986 have been observed.

A family of insects called chironomids accounts for most of the total insect mass at each study site every summer. Although small, they are present in very large numbers. Total insect mass has most often been larger at the study site near the ELF antenna than at other study sites. This trend has been observed during years before and after full-time antenna operations commenced. The larger masses near the antenna are almost entirely due to greater numbers of collector-gatherer, collector-filterer, and shredder insect groups at the antenna study site.

Conceivably, an ELF EM field exposure effect, if it were to occur, might impact only certain species of aquatic insects. The impact could go unidentified in analyses of total insect mass. For this reason, the masses of six distinct species are being determined and the results are analyzed separately. Three species of mayfly, two species of caddis fly, and a species of chironomid are monitored once a month throughout the year.

The emergence of these species is quite predictable on the basis of degree-days. The results of the studies have been analyzed from that perspective for each year. Some relatively slight variations between sites and between years have been observed. The variations do not appear to have a relationship to ELF EM field intensities.

Collectively and individually, observed variations in aquatic insect mass are largely explained by river flow rates and water temperatures. Cumulative degree-days is a reliable predictor of the vigor of the aquatic insect community.

4.3.3.3 Leaf Pack Colonization Patterns. Aquatic insect colonization on leaves is being studied by anchoring packs of alder leaves in the river at the study sites, then periodically removing them to study the resident insects. Some packs consist of current-year green leaves, and others consist of dry leaves

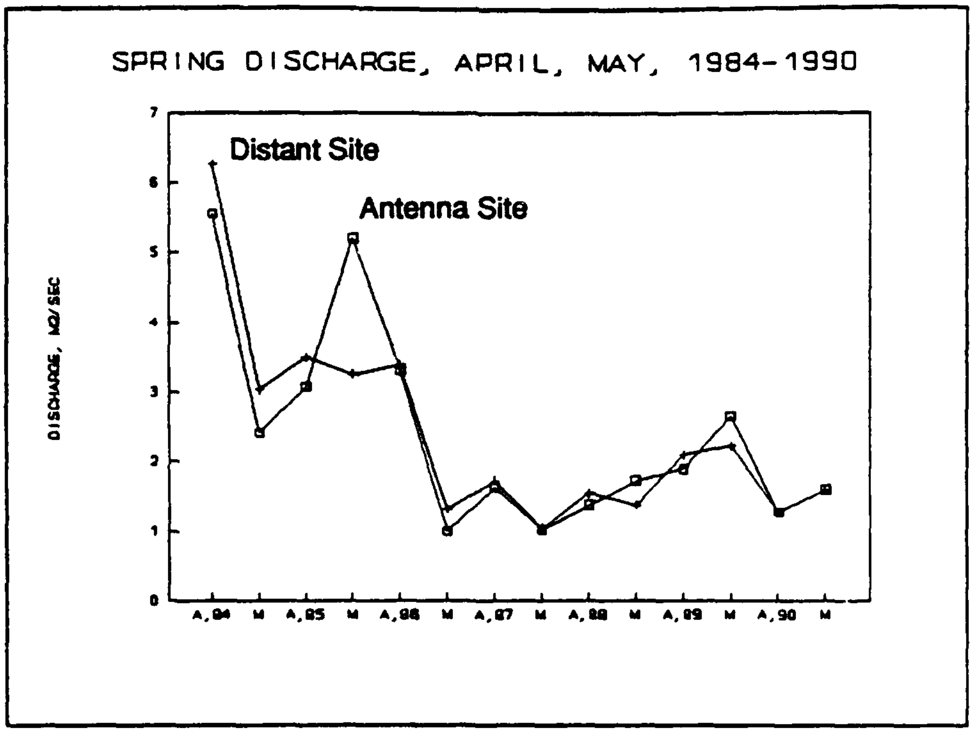


FIGURE 43. REDUCED SPRING FLOW HAS OCCURRED IN THE FORD RIVER SINCE 1987.

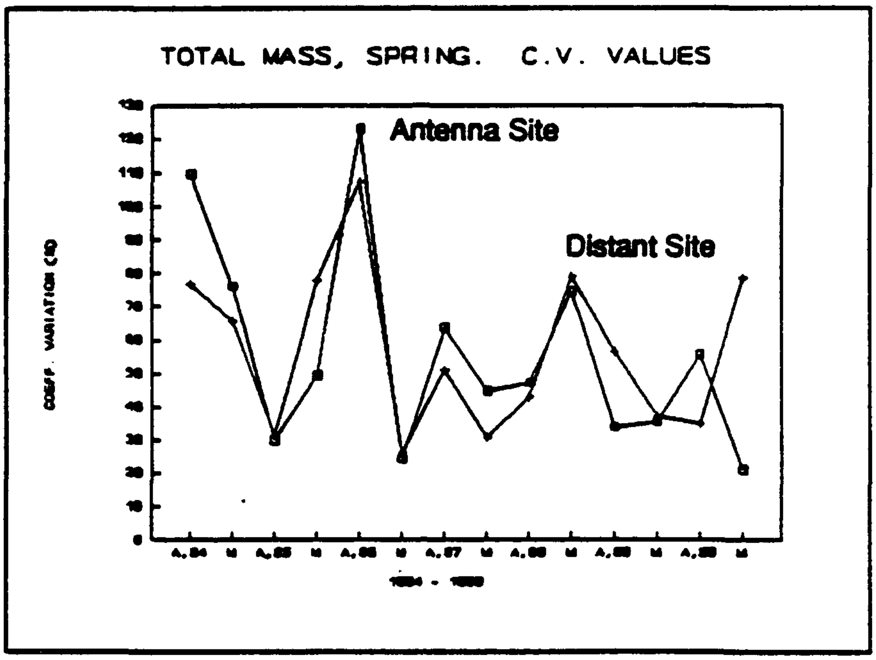


FIGURE 44. REDUCED SPRING FLOW IN THE FORD RIVER SINCE 1987 HAS REDUCED THE VARIABILITY OF AQUATIC INSECT BIOMASS.

from the previous autumn. Six samples from each site (42 green leaf packs and 42 autumn leaf packs) are analyzed each year. The samples are examined after four weeks of colonization in the river.

Insects have a preference for processing green leaves. However, fewer species have been observed on green leaves, particularly at the distant site. There has been a general trend over the years of few species on all leaf pack samples (algal communities have shown similar trends; see Section 4.3.2). The number of individuals within each species relative to other species, called evenness, also has been decreasing. These two trends are clearly illustrated in Figures 45 and 46.

Despite the decreasing trend observed in numbers of species, the numbers of individual insects on the samples have remained fairly constant over the years. The majority of the insects has consistently been chironomids, and in fact, their dominance on leaf packs has increased somewhat in most succeeding years at each study site.

No relationship has yet been found between observed variations in insect colonization and 76 Hz EM field exposure. River flow, water temperature, and cumulative degree-days are the main influences.

4.3.3.4 Leaf Pack Insect Mass. The total mass of insects on leaf pack samples remained much the same at each study site from 1984 until 1989. Insect mass increased in 1989 for unknown reasons.

The increase in mass was not sustained in 1990, however, except on autumn leaf packs at the distant downstream site. No conclusions have been developed as yet from these observations.

4.3.3.5 Individual Insect Weights. Two species of mayfly and a species of stone fly feed on leaves during the autumn, grow vigorously during the winter months when the water is cold, and then emerge from the river the following spring. Their growth has been monitored, and no consistent differences in growth have been observed between sites or from year to year. Thus far, there has been no indication that insect growth has been affected by ELF EM field exposure.

4.3.3.6 Green Leaf Insect Feeding. Insects have consumed fresh leaves at a relatively consistent rate at the antenna site and at the distant downstream site each year. The rate has varied somewhat from year to year, however, apparently in response to water temperature and to some extent to water flow. Water temperature affects insect feeding. No relationship has been established between ELF EM exposure and insect consumption of green leaves.

4.3.3.7 Autumn Leaf Insect Feeding. The study of insect consumption of autumn leaves was discontinued after the 1990 season. There was a need to conserve project resources, and autumn leaf processing studies were not critical to the success of the project. Additionally, autumn leaf processing

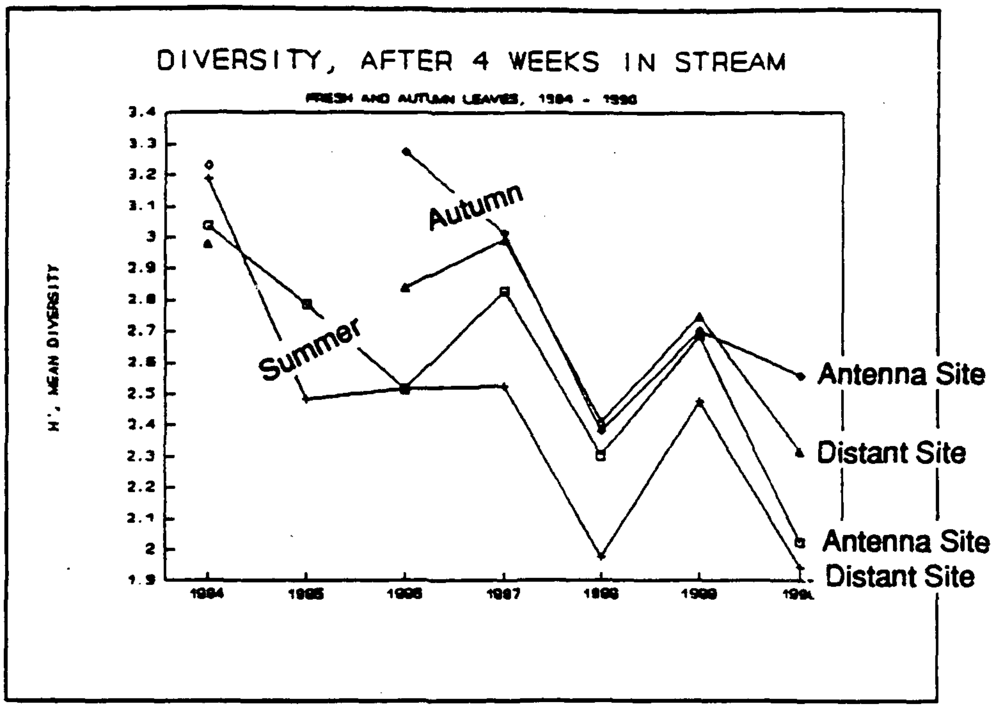


FIGURE 45. THE DIVERSITY OF INSECTS ON LEAF PACKS HAS BEEN STEADILY DECREASING AT THE FORD RIVER STUDY SITES.

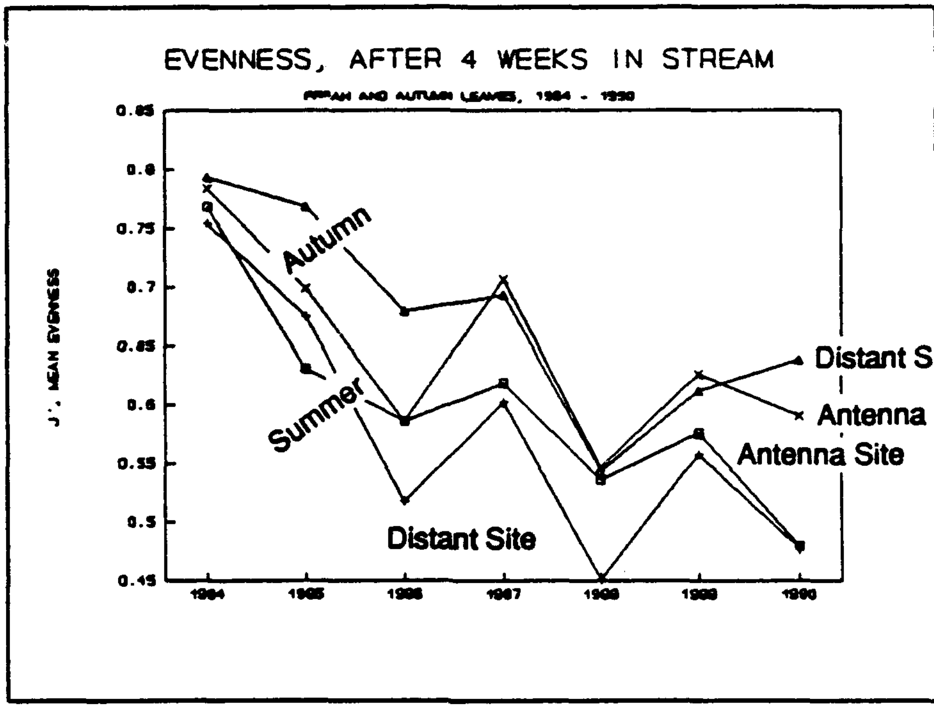


FIGURE 46. THE EVENNESS OF INDIVIDUALS IN EACH INSECT SPECIES HAS BEEN STEADILY DECREASING AT THE FORD RIVER STUDY SITES.

differed between the antenna study site and the distant study site before full-time antenna operations commenced as well as afterward. Confident conclusions could not be drawn from the observed results.

4.3.4 Fishes Project Results

The fishes project includes two separate studies. Fish species, their numbers, their condition, and their movement patterns are monitored for all but brook trout in one study. Brook trout are the most popular sport fish in the Ford River, so the second study focuses entirely on them. Their number and condition and their seasonal movements are monitored as conditions change in the Ford River.

4.3.4.1 Fish Species and Abundance. Fishes are caught in nets at the ELF antenna study site and at the distant study site to determine species. Catches are made daily for about 40 to 70 days during the summer each year (depending on river conditions), and the fishes are released after they are identified.

Species that have been netted at the study sites since 1984 are listed in Table 9. Differences in species between the two study sites have been observed to some degree every year. The differences in number for five of the most common species and all other species combined are shown in Figure 47. The data suggest that ELF EM field exposure has not influenced the species of fishes, or the numbers in each species at the study sites. No significant changes in the condition (e.g., average size) of netted

fishes have been observed, either. Water temperature and river flow are principal environmental factors that influence fishes in the Ford River from year to year.

4.3.4.2 Fish Movement Patterns. Large fishes of the most common species that are caught are marked so that their movements can be tracked after they are released. Most fishes that have been marked and found again have been found upstream or downstream in about the same numbers. The data obtained through 1991 do not indicate that ELF EM field exposure has any effect on fish movement patterns.

4.3.4.3 Brook Trout Migration Patterns. As the Ford River water temperature increases from spring to early summer, brook trout move upstream from the downstream distant study site past the ELF antenna crossing to Two Mile Creek. Their movement is in the opposite direction as autumn approaches and the river water cools. The spring-summer migration is being monitored to observe whether 76 Hz EM fields produced by the ELF antenna might have an undesirable influence on seasonal migration.

TABLE 9. FISHES IDENTIFIED AT THE FORD RIVER STUDY SITES

Most Frequent	Less Frequent	Least Common
White Sucker	Sea Lamprey	Northern Hog Sucker
Common Shiner	Brown Bullhead	Pumpkinseed
Blacknose Dace		Northern Brook Lamprey
Longnose Dace		Hornyhead Chub
Creek Chub		Fathead Minnow
Pearl Dace		Carp
Burbot		Smallmouth Bass
Rock Bass		Coho Salmon
Mottled Sculpin		Rainbow Trout
Blackside Darter		Alewife
Northern Pike		Golden Shiner
Brook Trout		Northern Redbelly Dace
Central Mudminnow		Bluegill
Largemouth Bass		

The numbers of brook trout captured, marked, and then released at the downstream distant study site have varied from week to week and from year to year. For example, Figure 48 shows that more brook

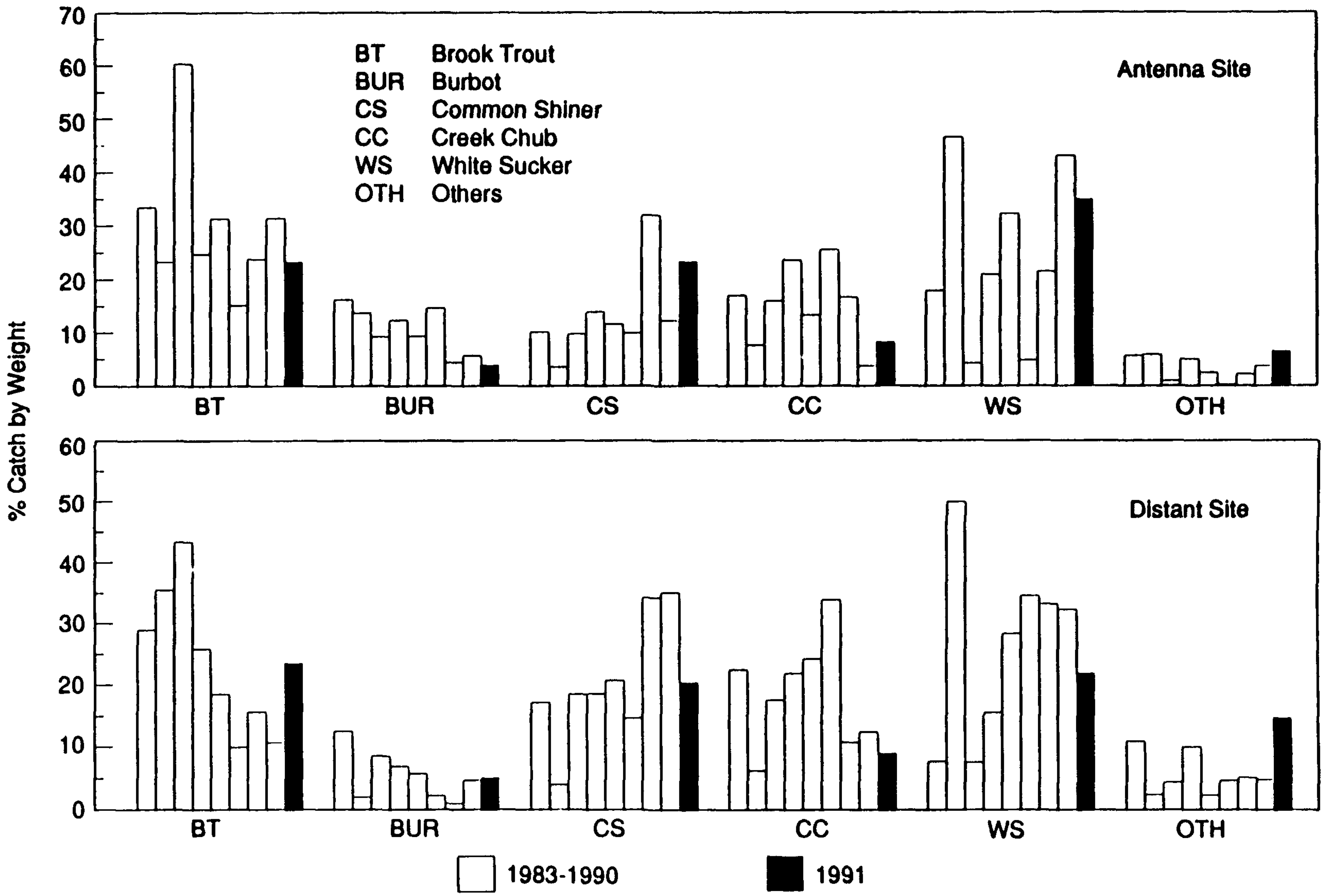


FIGURE 47. FISHES AT THE FORD RIVER STUDY SITES APPEAR NOT TO BE AFFECTED BY ELF EM FIELDS.

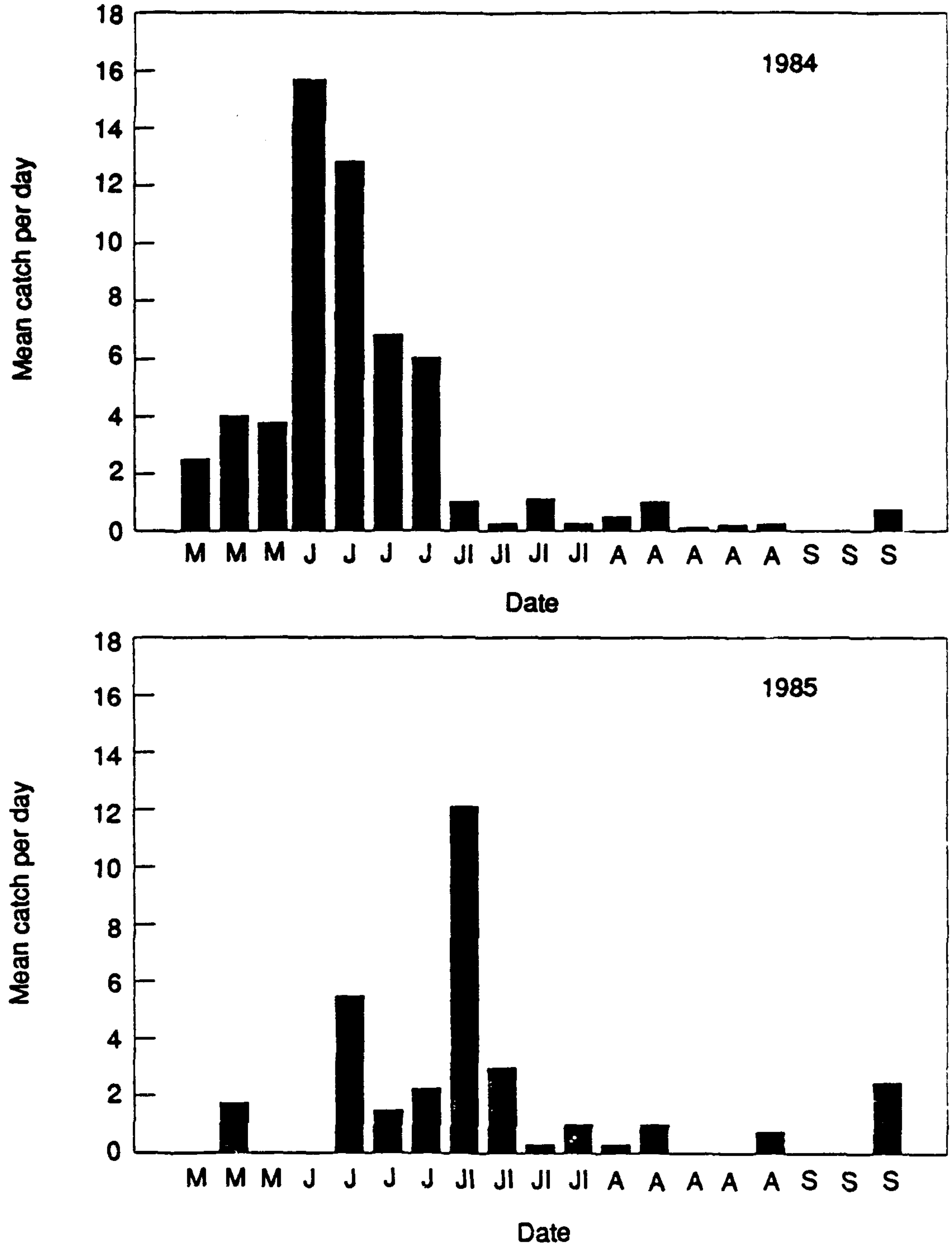


FIGURE 48. THE NUMBERS OF BROOK TROUT CAUGHT AT THE FORD RIVER DISTANT SITE VARIED WEEKLY AND YEARLY BEFORE THE ELF TRANSMITTING ANTENNA BECAME OPERATIONAL.

trout were caught, and were caught earlier, in May and June of 1984 than in 1985. The ELF antenna was not operated in those years. About 18% of the marked fishes were recaptured at the antenna study site in 1984, and 13% were recaptured there in 1985.

The same catch pattern has been found at the downstream distant study site since the ELF transmitter started operating. Figure 49 shows the data for 1990 and 1991. Catches during the last two years have been lower than in 1984 and 1985, but the reduction has been due to weather and river conditions. The percentage of marked fishes recaptured at the antenna study site was lower in 1990, but higher in 1991 (10% and 34%, respectively), than in earlier years.

Only about 10% of the marked fishes moved from one study site to the other within about four days, both before and after the ELF antenna started operating. About 50% of the marked fish moved within about one week. The numbers moving over longer periods have varied widely from year to year.

The weekly and yearly variability in caught and marked fishes, and the lack of variability in the time taken for marked fishes to move from one place to the other, both lead to the same tentative conclusion: at least through 1991, the 76 Hz EM fields produced by the ELF antenna do not appear to have affected the behavior of brook trout in the Ford River. River flow and water temperature appear to be the principal determinants influencing brook trout movements.

4.3.4.4 Brook Trout Age and Growth. Brook trout caught at the antenna study site and at the downstream distant study site have differed in size (and therefore age) in all years. For example, most brook trout were 5 to 7 in. long at the distant study site, and 9 to 12 in. long at the antenna study site, in 1985 (before the antenna became operational). In 1990, after the antenna started transmitting, the fishes at the distant site were somewhat larger on average. There was practically no difference in average size in 1991. No indication has been found that exposure to ELF EM fields has an effect on brook trout of any age or size.

4.4 Engineering Support Project Results

Staff engineers from IITRI assist research teams conducting ecology studies in several ways. Engineering support has been provided since 1982, when it was necessary to consider electromagnetics as well as biology and ecology in selecting study sites. Activities have been summarized and reported for each year since then.[40, 41, 44-49] The 1991 report currently is in preparation.

Engineering assistance has included designing chambers for maintaining organisms under certain electromagnetic conditions at study sites (e.g., the slime mold and soil amoebae projects); analyzing enclosures used for the forest animals project to ensure that electromagnetic field conditions remained undisturbed; designing lightning protection for instruments used to record environmental factors; and designing shields to maintain certain electromagnetic conditions at field laboratories where animals are examined.

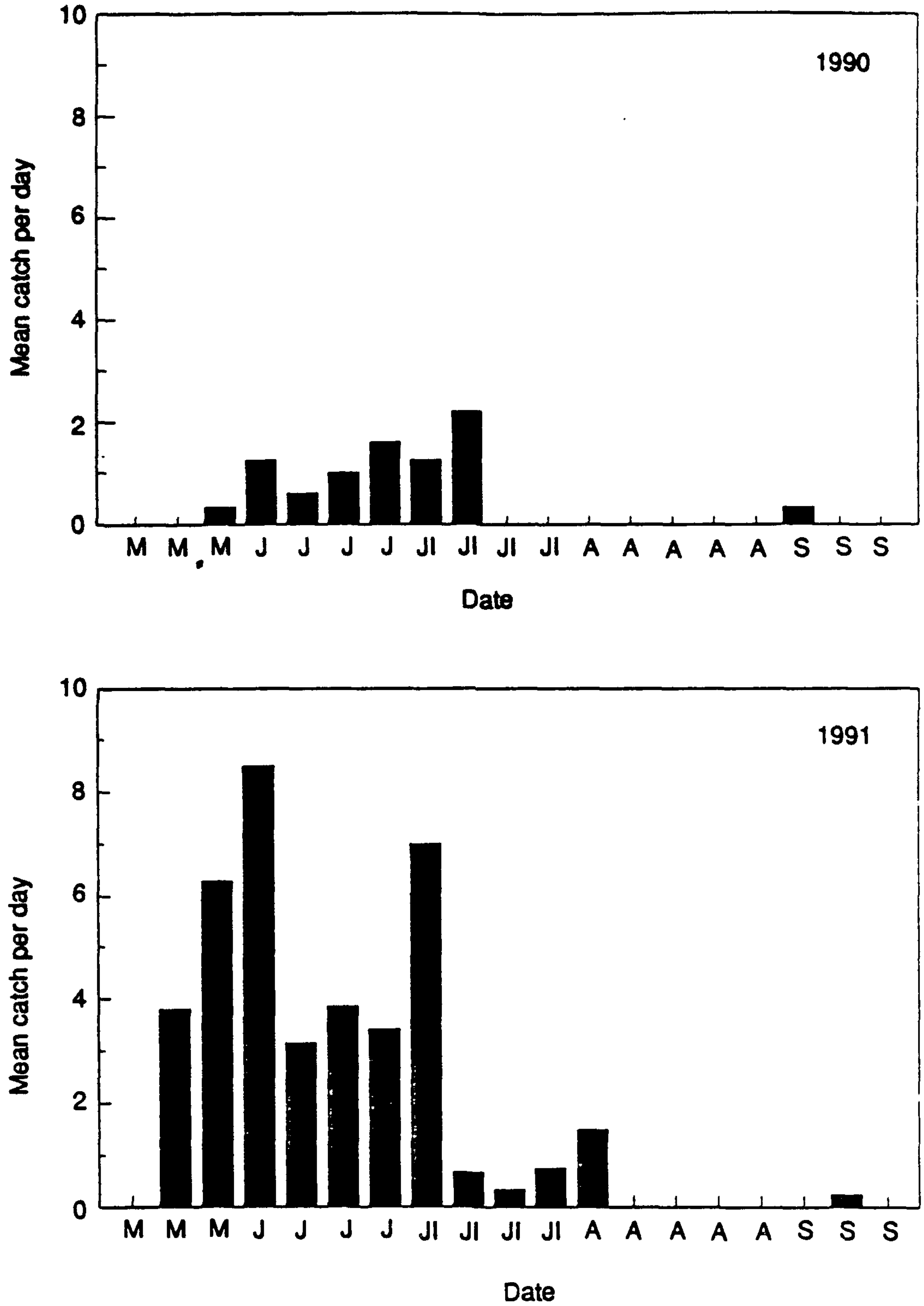


FIGURE 49. WEEKLY AND YEARLY BROOK TROUT CATCHES AT THE FORD RIVER DISTANT SITE HAVE CONTINUED TO VARY SINCE THE ELF TRANSMITTING ANTENNA BECAME OPERATIONAL.

FIGURE 50. ELECTRIC FIELDS ARE MEASURED IN AIR BY IITRI ENGINEERS AT ECOLOGY STUDY SITES.

The principal and most continuous support provided by IITRI's engineers is in measuring EM field intensities at all ecology study sites. Depending on the project, 76 Hz electric fields are measured in air (see Figure 50) and in soil (Figure 51), and magnetic fields are measured at the same frequency (Figure 52). The same three sets of measurements are made at 60 Hz at each site because 60 Hz fields are practically unavoidable. The main sources of the latter are power transmission and distribution lines.

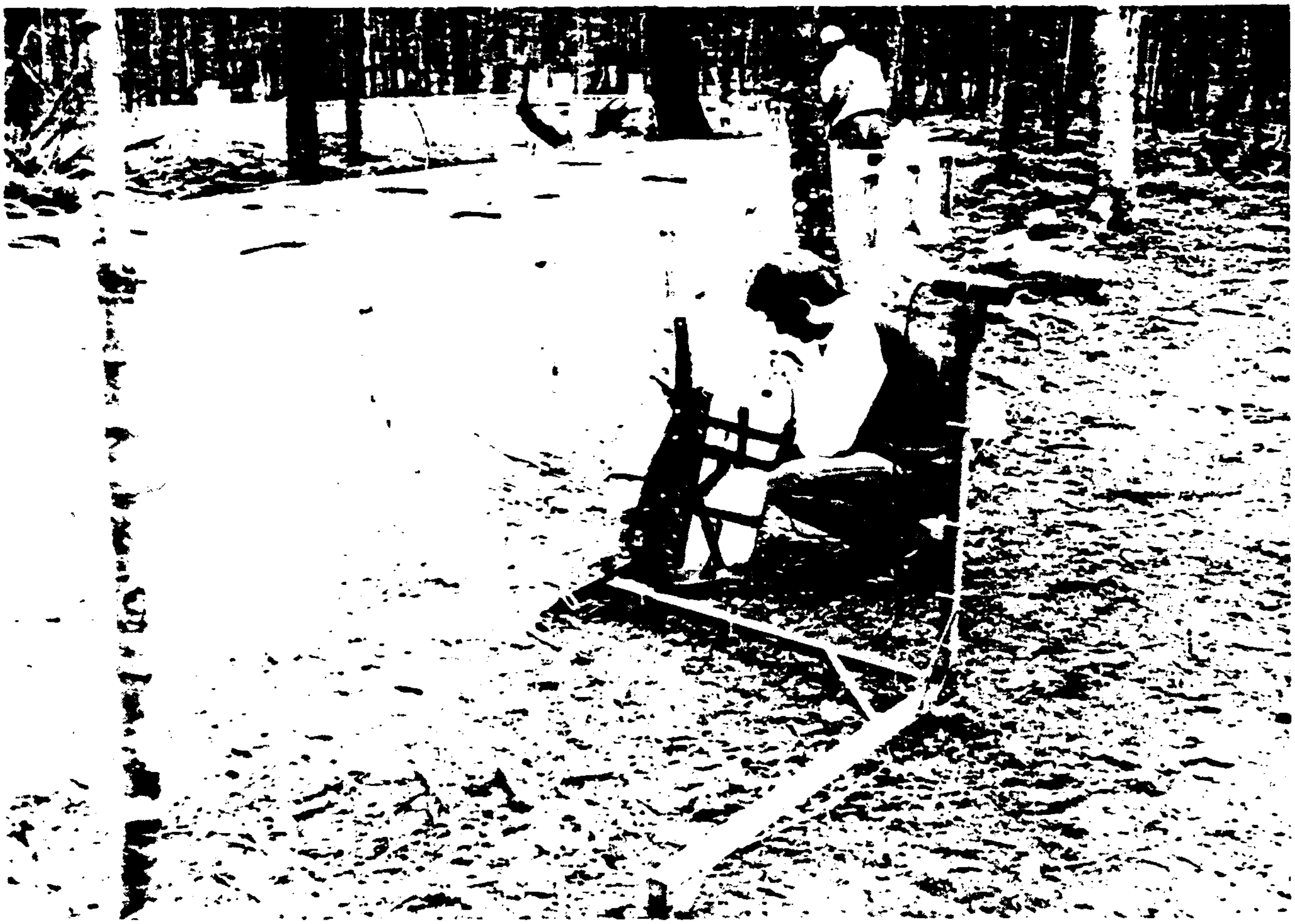


FIGURE 51. ELECTRIC FIELDS ALSO ARE MEASURED IN SOIL AT MOST ECOLOGY STUDY SITES.

4.4.1 Electromagnetic Field Exposures

Sixteen separate measurements are needed to characterize 60 Hz and 76 Hz electric and magnetic fields in air and soil at a point. The fields must be measured at many places on most ecology study sites, so a large volume of EM field intensity data is generated.

Research teams are responsible for analyzing and interpreting EM field exposure of plants and animals at their study sites, and the implications of that exposure, if any. Each investigator receives all measured EM field data from IITRI for this reason.

The ranges of 76 Hz EM field intensities that are produced at study sites near the ELF antenna (or ground terminals) when the transmitter is operating full-time are shown in Table 10. Data for the completed slime mold project, wetlands project, and bird species and communities project in Wisconsin are omitted from the table. Those data were presented earlier in describing the final results of those projects.

FIGURE 52. MAGNETIC FIELDS ARE MEASURED AT EACH ECOLOGY STUDY SITE.

4.4.2 ELF Transmitting Antenna Operations

The second factor in EM field exposure (the first being field intensity) is the length of time over which exposure occurs. Research teams receive information each year about the operation of the NRTF-Republic from IITRI to help analyze and interpret ecological monitoring results.

The ELF transmitting antenna did not operate before 1986. Testing of parts of the antenna system commenced in March 1986 with only several amperes in some parts of the system. The transmitter was on for only 160 hours in 1986, or 1.5% of the year. Testing continued until 1989, when the entire system started operating full-time at its rated power. A summary of operations is shown in Table 11.

TABLE 10. RANGES OF 76 Hz ELECTRIC AND MAGNETIC FIELD INTENSITIES PRODUCED AT ELF ANTENNA AND GROUND TERMINAL STUDY SITES WHEN THE ELF TRANSMITTER IS OPERATED FULL-TIME

Project	V/m in Air	V/m in Soil	Gauss
Soil Amoebae		0.02 to 0.05	0.002 to 0.010
Soil Bacteria and Fungi; Trees and Herbs	0.06 to 6.0	0.03 to 4.0	0.002 to 0.040
Soil and Litter Animals	0.05 to 0.07	0.05 to 0.06	0.002
Native Bees	0.05 to 40		0.002 to 0.030
Small Mammals and Nesting Birds	0.02 to 40	0.01 to 0.30	0.001 to 0.040
Bird Species and Communities	0.02 to 0.30		0.001 to 0.015
	V/m in Water		
Aquatic Ecosystem	0.030 to 0.100		0.001 to 0.020

TABLE 11. SUMMARY OF ELF TRANSMITTER FACILITY OPERATIONS IN MICHIGAN

		Total Operating Hours	Percent of Year
1986	Testing of parts of the ELF antenna system was begun at low power in March	160	1.5
1987	Testing of parts of the ELF antenna system continued at slightly increased power	400	4.5
1988	Testing of parts of the ELF antenna system continued and reached half-power	1000	11.5
1989	Testing was completed at half-power, and full-time operations commenced	5100	58.0
1990	Full-time operations continued throughout the year	8200	93.5

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